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STRATIGRAPHY AND PALEOECOLOGY OF THE
MORRISON FORMATION,
COMO BLUFF, WYOMING

by

Melissa V. Connely

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

2002

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ABSTRACT

Stratigraphy and Paleocology of the Morrison
Formation, Como Bluff, Wyoming

by

Melissa V. Connely, Master of Science
Utah State University, 2002

Major Professor: Dr. W. David Liddell
Department: Geology

The Morrison Formation at Como Bluff, Wyoming, has been historically known for containing a rich source of Late Jurassic vertebrate fossils. However, when collected, most of these fossils were not positioned into a stratigraphic or sedimentologic framework. Research shows that the Morrison Formation at Como Bluff can be divided into three members. These members can be identified by lithologic and paleontological characteristics. The lower Morrison members include the Windy Hill Member and the recently described Lake Como Member. The Windy Hill Member primarily contains near-shore marine sandstone. Megavertebrate fauna is lacking. The Lake Como Member contains illitic clay in red and green mottled paleosols with caliche and thin sandstone beds. The fauna typically consists of large saurian and ornithischian dinosaurs. The upper Morrison Formation includes the Talking Rocks Member. This member contains gray-green smectite-rich mudstones. The Talking Rocks Member is generally calcareous and appears to have a megavertebrate fauna similar to the Lower Morrison. The upper

part of this member is typically non calcareous and the fauna is more aquatic with turtles, crocodiles, fish and smaller ornithischian dinosaurs, including some species thought to be restricted to the Cretaceous Period.

The contact between the Morrison Formation and the overlying Cloverly Formation is placed at the base of the Cloverly conglomerates, which are present throughout the region. In some areas, this boundary coincides with the Jurassic/Cretaceous boundary. However, in sections of the study area, a zone of kaolinitic carbonaceous shale with Cretaceous-like plant material can be found just below the Morrison/Cloverly contact. If this bed is Cretaceous in age, then the Morrison Formation at Como Bluff is in part Early Cretaceous and not restricted to the Late Jurassic.

(118 pages)

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INTRODUCTION

General Statement

The Morrison Formation at Como Bluff, Wyoming, is the type locality for many important Jurassic fossils and is particularly well known for the dinosaur quarries of the late O.C. Marsh, paleontologist for Yale University's Peabody Museum in the late 1880's (Ostrom and McIntosh, 1966). Many of these fossil skeletons can be seen on exhibit in museums throughout the world (Breithaupt, 1998). Although the Morrison Formation has been well studied (Appendix E), especially in the Colorado Plateau area by the Morrison Research Initiative (<http://yuma.colostate.edu/~cwis70/morrison.html>, 1999), detailed stratigraphic research is lacking for much of Wyoming. This lack of stratigraphic information hampers the use of the fossil remains in paleoecological interpretation. In addition, it is difficult to correlate this site with better known localities for studies such as faunal migration and immigration, which require linking sites in Wyoming to those in Colorado and Utah.

The Morrison Formation at Como Bluff is predominantly non-marine in origin with the exception of a thin marine sequence, known as the Windy Hill Sandstone, at the base of the formation. The formation is bounded at the base by the J5 unconformity, located just below the Windy Hill Sandstone (Peterson, F., 1994). The top of the formation is bounded by the K1 unconformity. This upper contact has proven to be difficult to locate and thus a source of debate for the age of the formation. The Morrison Formation is composed of reddish (at the lower half) and greenish to dark gray mudstone

(the upper half) interbedded with limestone and sandstone beds. Biozones of both vertebrate and invertebrate species exist throughout the section.

This study was initiated to provide a detailed stratigraphic framework to complement existing paleontological data. The objective was to provide member identifications complete with biostratigraphic zones as a base section for stratigraphic correlation with other Wyoming sites and those of the Colorado Plateau. Furthermore, by incorporating known taxonomic and taphonomic data into this framework, a better understanding of the paleoecology of the Morrison Formation can be achieved.

Geographic Location and Tectonic Setting

The study area is located on the southern flank of a southeast-northwest trending anticline in Albany County, Wyoming. The outcrop is labeled Como Ridge on the Aurora Lake, WY, 7.5 minute quadrangle USGS map, 1971, and extends eastward into the Pine Tree Ridge, WY, 7.5 minute quadrangle. The study area is found at the locations: T. 22 N., R. 76 W. sections 3, 4, 5, and 6, and T. 22 N., R. 77 W. sections 1, and 12 (Figure 1). Although many of the historic quarries are located farther west along Como Ridge, the sites listed above were chosen for several reasons. First, access was granted by the Carlin Ranch, owner of the study area under the leasing permit through Dr. Robert. T. Bakker and the Wyoming Dinosaur International Society. Second, good exposures exist, which are needed for detailed stratigraphy and facies analysis. Finally, the site is actively being excavated for fossil remains, providing a rich and continuing source of paleontological data.

The Morrison Formation is found throughout the Western Interior. According to F. Peterson (1994) sediments that make up the formation were deposited in a broad, shallow basin on the west and southwest side of the North American craton and extend from northern Arizona and New Mexico north to the Canadian border. The formation was deposited primarily during the Late Jurassic back-bulge depozone of the Cordilleran foreland basin system (DeCelles and Currie, 1996). The paleolatitude at the type section was approximately 35-38°N (Peterson, F., 1994). Clastic sediments that make up the formation in the Colorado Plateau area are believed to be from the Western Elko Highlands in Nevada and the Mogollon slope of Arizona and California (Peterson, F., 1994). Windblown volcanic material may have come from the magmatic arc off the continental margin in the southwest. In the northern part of the Western Interior, clastic sediments that make up the Morrison Formation may have come from the Ancestral Front Range (Peterson, F., 1994), Boulder High of Montana and Idaho and/or the craton from the northeast (Peterson, J.A., 1994).

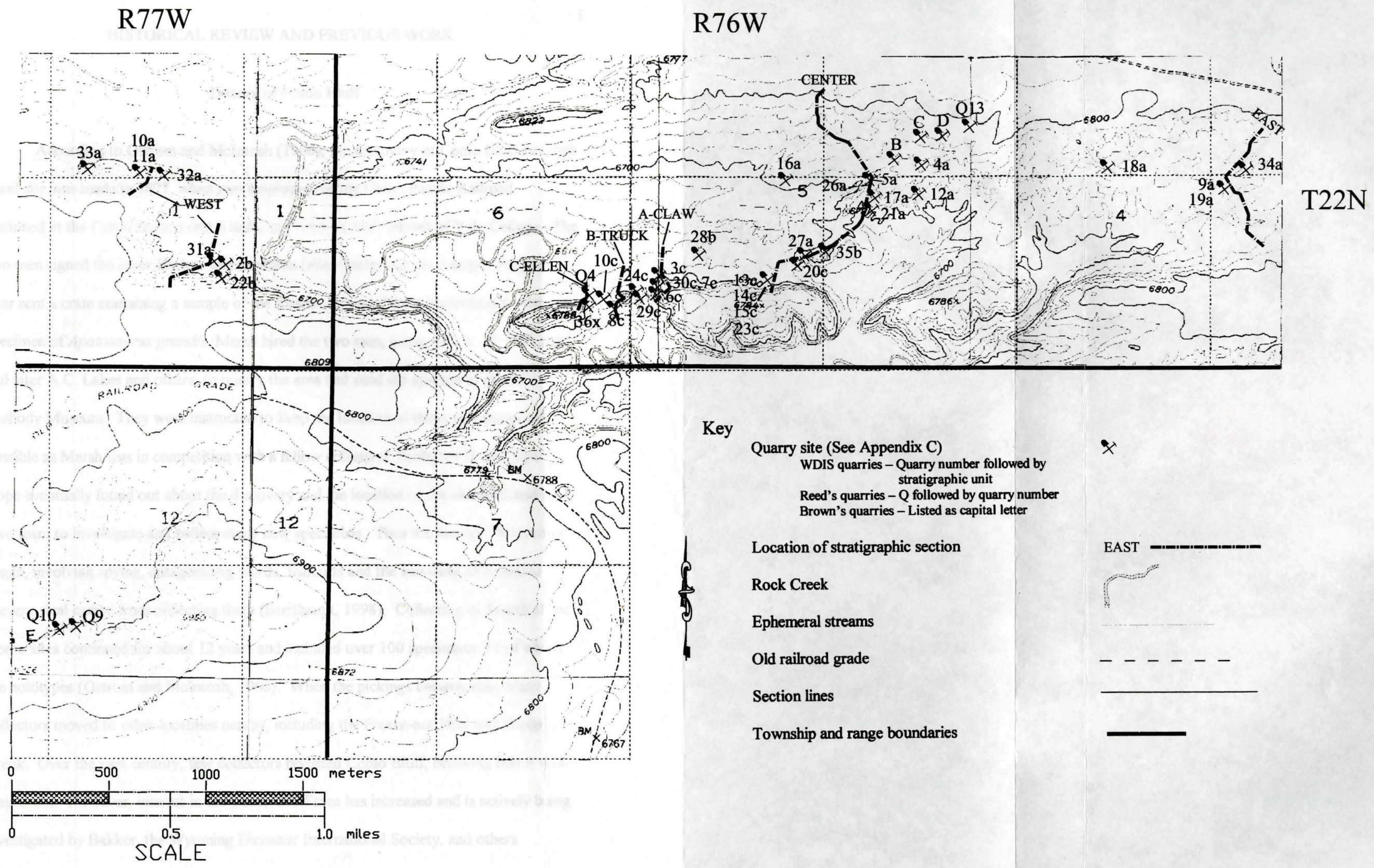


FIGURE 1—Map of the Como Bluff study area (Drafted by Arch Swank)

HISTORICAL REVIEW AND PREVIOUS WORK

History of Como Bluff

According to Ostrom and McIntosh (1966), the discovery of Como Bluff as a rich fossil site was made in 1877, when two employees of the Union Pacific Railroad stationed at the Como Station sent a letter to Professor O.C. Marsh of Yale College. The two men signed the letter Harlow and Edwards (alias Carlin and Reed respectively) and later sent a crate containing a sample of the fossils. Some of these bones became the type specimen of *Apatosaurus grandis*. Marsh hired the two men, along with S. W. Williston and later A.C. Lakes and others, to quarry the area and send the specimens to the Peabody Museum. They were instructed to keep the location as much of a secret as possible as Marsh was in competition with a fellow colleague, Professor E. D. Cope. Cope eventually found out about the discovery and the location of the sites and sent his own team to investigate and collect many new specimens. Thus the famous "bone wars" began, involving spying, antagonizing words, fistcuffs and the smashing of fossils to prevent rival camps from collecting them (Breithaupt, 1998). Collecting by Marsh at the Como sites continued for about 12 years and included over 100 specimens, 81 of which are holotypes (Ostrom and McIntosh, 1966). When the pickings became slim, many collectors moved to other localities nearby, including the Freeze-out Hills and Sheep Creek. Over the past century, few collectors revisited Como Bluff, believing that it was played out. However, interest in the Como Bluff area has increased and is actively being investigated by Bakker, the Wyoming Dinosaur International Society, and others.

Previous Work on the Morrison Formation

Over the past 100 years, the Morrison Formation in the Western Interior has been well studied by many writers. Various member names have been applied to the formation, especially in the Colorado Plateau area. Until recently, formal member names have not been given to the Morrison Formation in Wyoming. An attempt was made by Allen (1996, 2000). At this time, it is not clear whether the geologic community has accepted the formal member names proposed by Allen. Allen proposed the names of Lake Como Member for the lower half of the Formation and the Talking Rocks Member for the upper half of the Formation. He left the Windy Hill Member in the Sundance Formation, where it was originally placed by Pipiringos in 1972.

In the early 1990's, a special project, the Morrison Research Initiative, was developed in conjunction with the National Park Service and the United States Geological Survey. The goal of this project was to develop a unified geological framework for the Morrison Formation, to establish ages for the different members, and to reconstruct the paleoclimate and ecosystem during Morrison time throughout the Western Interior. The result of this study was the publication of many papers, most of which were presented at a special symposium titled *The Upper Jurassic Morrison Formation: An Interdisciplinary Study*, at the Denver Museum of Natural History, Denver, USA, May 26-28, 1994 (Carpenter et al., 1998). The resulting publications are in a two-part volume of *Modern Geology*, v. 22 and 23, where over 60 new papers on the Morrison Formation can be found. However, because this study focused on the whole Western Interior, detailed stratigraphic studies were not often included. Furthermore, the

focus of the study was on the Colorado Plateau and vicinity. Although the study provided a new wealth of information to the scientific community, our knowledge of the Morrison Formation is still incomplete.

Type Locality

The Como Bluff sites are contained within a unit previously called the "Atlantasaurus Beds," now known as the Morrison Formation. The type locality of the Morrison Formation is near Morrison, Colorado, approximately 100 miles south of Como Bluff. It was first described by Cross (1894, p. 2) when he stated:

The name [Morrison Formation] is given from the classic locality at Morrison, near Denver, where the first gigantic dinosaurs from this formation were obtained. [It consists of]... prevailingly greenish, pinkish or gray shales and marls. Sandstone occurs at the base and is also intercalated at numerous horizons in the upper part of the section.... Gypsum is locally developed and becomes prominent to the east. A thin limestone often forms the base of the formation.

Eldridge (1896) also described the Morrison Formation and was given credit by some as the one who named the formation. However, as Peterson and Turner (1998) pointed out, Cross should be given the credit as his description was first in print and was re-cited by the author and others in 1899. Waldschmidt and LeRoy in 1944 measured a section along the Alameda Parkway near Morrison, Colorado, and proposed it as the type section for the Morrison Formation. This section is still used today as the type locality. Peterson and Turner redescribed the Morrison Formation in 1998 using the type locality and other sites nearby. They divided the formation into three informal units instead of the six units previously described by Waldschmidt and LeRoy (1944).

According to Peterson and Turner (1998), the Morrison Formation at the type locality can be divided into three distinct units. In most areas, the Morrison Formation is bound by the J5 unconformity at the base and the K1 unconformity at the top. However, at the type area, the Ralston Creek Formation separates the Morrison Formation from the J5. Peterson and Turner (1998, p. 14) as noted below briefly describe the members.

Lower member. At the base of the Morrison at the type locality is a sandstone unit 2.1m (7ft) thick that is very light-brown, fine grained, cross bedded to very thin bedded, and locally contains mudstone rip-up clasts at the base. . . . Where two or more sandstone beds are present, thin red, gray, to grayish-green mudstone beds separate the sandstone beds. . . . They [the sandstone beds] are thin, laterally amalgamated, locally vertically stacked, ribbon-type, fluvial channel sandstone beds.

Peterson and Turner (1998) further added that the lower member includes fluvial sandstone beds that scour down into the Ralston Creek Formation below and contain small chert and quartz pebbles up to 1.4 cm in diameter. These fluvial sandstone beds are laterally discontinuous and pinch out northward. Turner and Peterson (1999) listed this lower member, in general using data from throughout the Western Interior, as containing dinosaur Zone 1 and most of 2, which include: *Allosaurus*, *Haplocanthosaurus*, and *Stegosaurus* in Zone 1 and *Coelurus*, *Diplodocus*, *Camptosaurus*, *Apatosaurus*, and *Edmarka* in Zone 2. In their study, they show that Zone 1 is "poorly defined" and has a low diversity. Zone 2 shows a marked increase in diversity and the appearance of many long-range taxa. Sohn and Peck (1963) also listed this lower member as having a charophyte zone *Theriosyneocum wyomingense*. In addition, Turner and Peterson (1999) listed this member as including the charophyte and ostracode Zones 1, 2, and 3 as described by Schudack et al. (1998). The middle member is described below (Peterson and Turner, 1998, p. 15).

Middle member. The middle member is 59.1 m (194 ft) thick at Alameda Parkway where it consists mostly of mudstone interbedded with thin limestone or scarce dolomite beds. Grayish-green or gray colors dominate the middle and dark reddish-brown colors are more common near the base and top. The carbonate beds are most abundant in the middle and are fewer in number toward the base and top. . . . The basal contact of the middle member is at the base of the lowest mudstone bed and at the top of the highest sandstone bed of the lower member.

Peterson and Turner went on to report that most of the limestone beds are thin, less than 0.6 m thick. One bed near the base, however, is about 1-3 m thick. Keller (1953) noted that there was a clay change above this limestone bed from kaolinitic and illitic to smectitic clays. Peterson and Turner (1998) suggested that this combination can be used as a stratigraphic marker for correlating measured sections in the Front Range foothills of Colorado. Also noted was an abundance of charophytes by Waldschmidt and LeRoy (1944). According to Schudack et al. (1998) and Sohn and Peck (1963), these fossils can be used for environmental interpretations and, in some cases, as boundary markers. They list this member as containing the charophyte and ostracode Zone 4. This member also contains the dinosaur Zone 3 of Turner and Peterson (1999), which include *Ceratosaurus*, *Drinker*, and others. Zone 3 marks the end of many long-range taxa and the beginning of some new species. The upper member is described below (Peterson and Turner, 1998, p. 16).

Upper member. Interbedded sandstone and mudstone comprise the upper member, which are 16.2 m (53 ft) thick at Alameda Parkway. . . . The sandstone beds are very light brown, fine grained, tend to have cross bedding that is faint or obscure, and contains scattered small pebbles of chert or scarce quartz in many but not all localities. . . . The mudstone beds in the upper member are dark reddish brown light grayish green, or gray and tend to be noncalcareous. . . . Mudstone is the dominant lithology in many places but the presence of sandstone is what distinguishes the upper member from the underlying middle member.

Turner and Peterson (1999) described the upper member of the Morrison Formation as containing the charophyte and ostracode Zone 5 and the dinosaur Zone 4. This zone marks the end of most of the long-range taxa. They did not indicate that any new taxa develop at this zone, with the possible exception of *Amphicoelias*.

The upper contact of the upper member (and the formation) is on top of a thick sequence of paleosols and is overlain by the base of the Lower Cretaceous Lytle Formation. The contact is difficult to identify in many places. Meyers et al. (1992) described several criteria for differentiating sandstones from the Morrison Formation in the Big Horn Basin of Wyoming from the overlying Cloverly Formation. These criteria are based on the petrography of the sandstone beds within the formations. Some stratigraphers use paleontological criteria to identify the upper contact.

Previous Work on the Morrison Formation at Como Bluff, Wyoming

Attempts have been made to describe the stratigraphy at the Como Bluff area by various researchers including Pipiringos (1957), Allen (1996), Bakker (1998), F. Peterson (1994) and Peterson and Turner (1998). The basal unit is the Windy Hill Sandstone, previously described by Pipiringos (1972) as the Windy Hill Member of the Sundance Formation and is best described as Member A in Pipiringos (1968). The type locality for this unit is in the nearby Freeze-out Hills. F. Peterson (1994) reassigned this member to the Morrison Formation based on the J5 unconformity located at the base of the Windy Hill sandstone. The Windy Hill Member is composed of fine-grained quartz sandstone or oolitic limestone containing fossil fragments, glauconite, and, in some cases, pterosaur tracks (Logue, 1977; Lockley et al., 1995).

Allen (1996) produced a stratigraphic section using a caliche horizon as a boundary between the upper and lower part of the formation. This marker is also known as the "Bakker Break" where the profile of the formation changes slope. Bakker (1998) described the unit below this marker as the "Apatosaurine Interval I," containing smectite-poor clays with the dominant apatosaurine species *Eobrontosaurus yahnahpin*. At a nearby location at Nine Mile Hill, Turner and Peterson (1999) described this lower unit as containing dinosaur Zone 1 and 2 while Schudack et al. (1998) described it as containing ostracode and charophyte Zones 2 and 3.

The upper part of the Morrison Formation at Como Bluff has been divided into two units or members by Allen (1996) and Bakker (1998). Allen described the unit as consisting of gray smectite-rich mudstone with thin limestone beds. This is followed by darker mudstone beds containing few resistant beds. Bakker (1998) listed the unit as containing the Apatosaurine Interval 2 at the lower part and Apatosaurine Interval 3 at the top. This upper portion is best known as containing the Breakfast Bench fauna (Bakker, 1986). At Nine Mile Hill, Turner and Peterson (1999) also broke this upper unit into two sections containing dinosaur Zone 3 at the lower half and dinosaur Zone 4 at the upper half. Furthermore, Schudack et al. (1998) identified the ostracode and charophyte Zone 4 and 5.

The contact of the upper member and the overlying Cloverly Formation (early Cretaceous) is difficult to identify and was subject to many debates. It has been proposed by Bakker (1990), that the Morrison could extend into the Cretaceous due to some fossil types found in the shales and mudstones located below the Cloverly Sandstone. Peterson and Turner (1998) and others looked at the Morrison at Nine Mile Hill and suggested that

the Morrison does not continue into the Cretaceous due to palynomorph (Litwin et al., 1998), and charophyte and ostracode (Schudak et al., 1998) studies. However, some fossil assemblages recently found in the Breakfast Bench area conflict with this theory (Bakker, 1990) and suggest that either the Morrison extends into the Cretaceous, or that Cretaceous-like vertebrates first developed in the Jurassic.

METHODS AND MATERIALS

Stratigraphy

Measured Sections and Sample Collection

Six stratigraphic sections in the Como Bluff area were chosen to be measured and sampled. The locations of these sections are shown in Figure 1. Three of the sections traverse most of the Morrison Formation. Only one of these three crosses the lower contact between the lower Sundance Formation and the overlying Morrison Formation. All other sections start in the Morrison Formation and cross the upper contact into the overlying Cloverly Formation. The three nearly complete sections were used to describe the thickness of the Morrison Formation and the major contacts between members. The main sections "East," "Central," and "West" are approximately 2.5 to 3 km apart. The smaller partial sections were used to define the upper Morrison/Cloverly contact and to place known quarries into the main columns (Figure 2, located in pocket).

The sections were measured with a Brunton pocket transit, a 50-m fiberglass tape and a 1.5-m Jacob staff. One or more samples were randomly collected at each lithologic change in the section. For each lithologic unit, notes were taken describing the lithology, color using the GSA rock color chart (Geological Society of America, 1995), bedding thickness, sedimentary structures, resistance to weathering, and any fossils assemblages present. Paleocurrent data from forsets found in the sandstone and bone orientation were also collected and rose diagrams were produced using Stereonett 2.46 (2000) and Oriana 1.06 (1994) software programs. All lithologic samples collected were reexamined in the

lab where thin sections of the more resistant rocks were made. The mudstone samples were examined using X-ray diffraction analysis.

X-Ray Diffraction Analysis

The mudstone samples, which appeared to be fresh and not altered by recent weathering conditions, were tested for their clay content using X-ray diffraction analysis. The data were obtained using a Phillips model 12045 X-ray diffraction system where X-rays from a Cu-target tube operated at a 35 kV and 15 ma passed through a goniometer containing a glass slide with a prepared sample. The scan was set to run between $2-\theta = 3^\circ$ to $2-\theta = 33^\circ$ at a scan speed of $2^\circ/\text{min.}$ and a step size of 0.05° .

The purpose of the X-ray scans was to find which clays were present in the samples. Therefore, only clay-sized particles from each sample were used in the analysis. For an oriented sample, 2 gm of dry sediment was mixed with 20 ml of distilled water. In some cases, the sample swelled and absorbed all of the water. In these few cases, the sample was reduced to 1 gm. After the sample was immersed in the distilled water, the sample was then shaken and/or stirred to disaggregate the sample and release the clay-sized particles. The sample was allowed to settle for 1 minute so that the clay-sized particles could be isolated based on Stokes Law (Krumbein and Sloss, 1963). One ml of sample was removed using a syringe submersed 1 cm from the surface. This new sample was transferred to a glass slide where it was allowed to dry at room temperature, orienting the particles.

Each oriented sample was then placed in the goniometer, as described above, and the scans were made. The resulting data were recorded in a Difftech 122D (1996)

computer software program and analyzed using the Jade 3.1 (1997) software program.

To confirm the presence of the smectitic clays in the sample, the slides were treated with ethylene glycol by placing them in a closed container with 20 ml of solvent in a 50-ml beaker in a drying oven at 65°C for 1 hour. The slides were then removed and scanned immediately using the same settings as before. Where smectitic clays were present, a shift in the peaks at the lower 2- θ angles was detected (Figure 3). To determine the existence of kaolinite, the slides were transferred to a kiln where they were heated to 550°C for 1 hour. Again, the slides were scanned using the same setting as before. Where kaolinite clays were present, the major peak (at approximately 12.3 2- θ) was no longer present in the second scan (Figure 3). The same procedure was used on a known sample of each clay type as a control sample. Results from the clay analysis were applied to the main stratigraphic column (Figure 2) and listed in Appendix A.

Petrographic Analysis

Samples from the resistant layers in the stratigraphic sections were made into thin sections and studied using petrographic methods. Twenty-five thin sections were made from sandstone, conglomerate, limestone, siltstone, caliche, and chert. Six of the better sandstone samples were stained for feldspars after being etched with hydrofluoric acid. Sodium cobaltinitrate was used to stain potassium rich feldspars and barium chloride and rhodizonic acid were used to stain the anorthite component of plagioclase. To determine compositional percents on a QFL (total quartz, total feldspar and total lithic) diagram, thin sections of the most resistant sandstones were point-counted using a modified Gazzi-Dickinson method 500 point count. Here, sand sized ($> 0.0025\text{mm}$) mineral grains

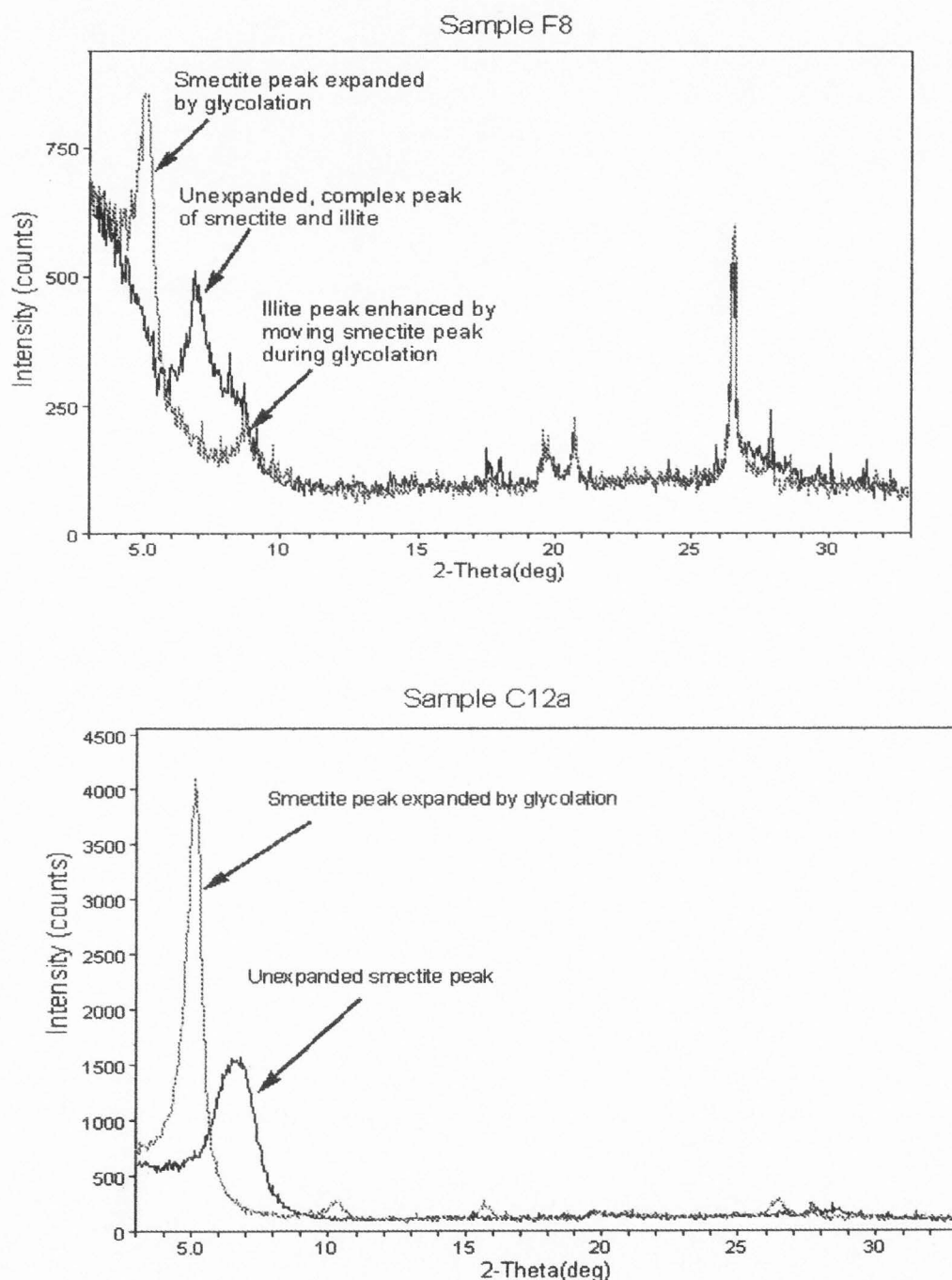


FIGURE 3—Graphs showing results from X-ray diffraction analysis. Sample F8 (top) shows an Illite/Smectite mixture. Sample C12a (bottom) shows a strong smectite peak. Sample A28 (both top and bottom, page 17) shows peak responses to different treatments.

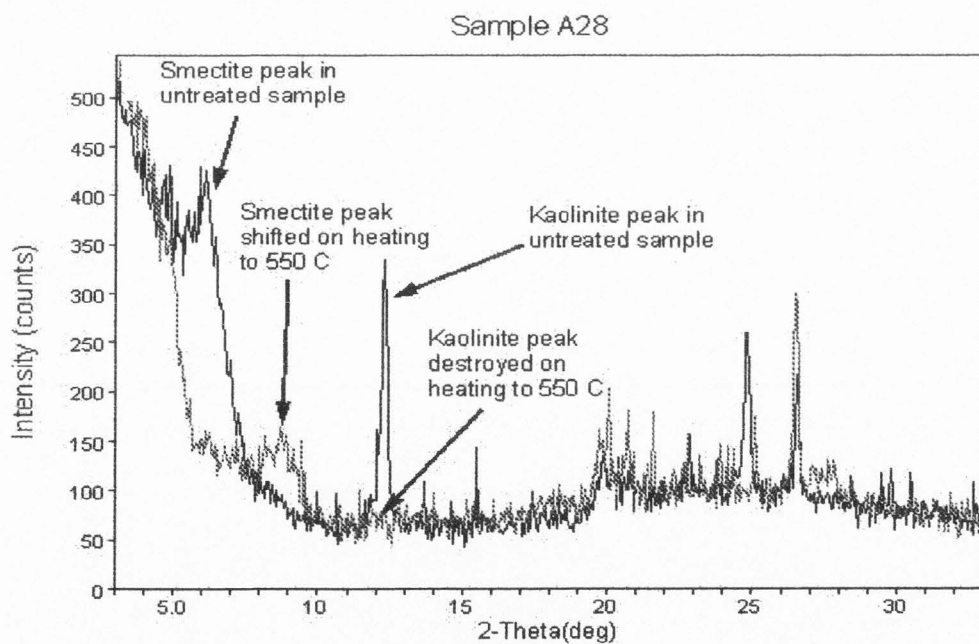
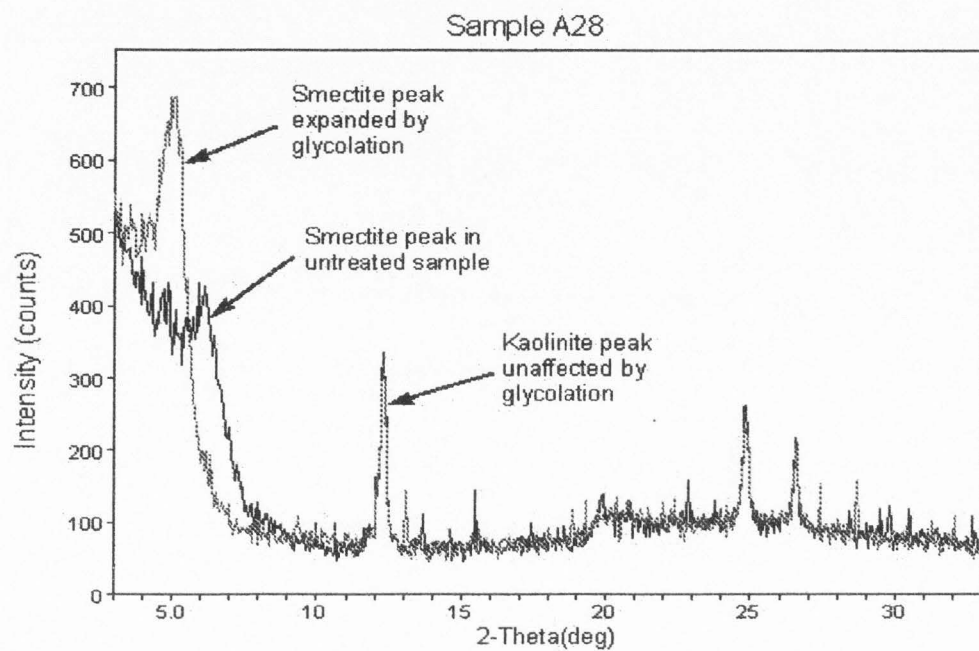


FIGURE 3—Continued.

within a rock fragment were counted as that individual mineral, which the GD method requires (Dickinson, 1970; Ingersoll et al., 1984). Modifications to the standard GD method include the addition of chert and chalcedony as part of total quartz. In addition to the basic QFL counts, other grains such as fossils were also noted (Table B.2, Appendix B). Quartz was subdivided into polycrystalline and monocrystalline quartz and the feldspars were subdivided into plagioclase and potassium-rich feldspar for future work. Lithics were not subdivided. Matrix and unknowns were not divided and listed as miscellaneous as they were difficult to tell apart due to the stains applied to identify the feldspar. These modifications to the standard GD method were used so that the environment of deposition and a more detailed description of the sandstone could be made as suggested by Ingersoll et al. (1984). In addition to the counts, other comments on lithology, mineralogy, grain size, roundness and sorting, and fossils present were made. All examinations of the thin sections were performed on a Meiji Techno ML 9000 series polarizing microscope and the data are listed in Appendix B.

Paleoecology

Sample Collecting

Paleontological samples and data were collected by the author and by various volunteers with the Wyoming Dinosaur International Society and added to information from previous collections. Samples for this study were collected and or recorded through small scale quarrying and surface collecting. All of the quarry methods involved removal of matrix with small hand tools and picks, reducing the amount of bias against smaller

vertebrate fossil types. In surface collecting, great care was given to locate and find smaller sized bone and other invertebrate fossils. In the quarries containing megavertebrate fossils, specimens were mapped and their orientation was recorded. In the "micro sites" or smaller vertebrate fossil localities, this was not always possible and thus samples were often collected in bulk. Screen washing was not employed, as the bone specimens in most of the upper quarries were brittle and too delicate to survive this method of recovery. Therefore, some biases may be present against very small material. However, to compensate for this bias, some material was reexamined under a microscope. Each fossil locality was given a site name and mapped into the main stratigraphic column. At each site, data such as the species type, number of species, number within a species, and taphonomy were recorded (Appendix C).

Quantitative Analysis of the Fossil Assemblages

To determine the paleoecology of the Morrison Formation at Como Bluff, quantitative analyses of the fossil assemblages were made. The focus of these tests was to determine the diversity and the fossil relationships within the formation. With this information, some inferences as to the types of communities that may have existed in Morrison time could be made. To do this, however, several assumptions must be identified. It is understood that the fossil record includes "limitations of the evidence" (Ager, 1963). Such limitations involve both the way a fossil is preserved (a fossilization bias) and the way the fossil is interpreted (interpretation bias). To understand the ecology of a system, it must be assumed that the system represented by the fossil record was a stable system, one that was self-regulating or homeostatic. Second, the relationships

within the community were similar in life as well as in death unless evidence exists to support the contrary. Third, the fossil assemblage represents the average community and not a microenvironment or microcommunity such as an oasis in a desert. Finally, fossilization and interpretation biases must be minor.

With these limitations and assumptions in mind, the paleontological data can be studied using quantitative methods. To describe the diversity of each assemblage, the Brillouin diversity measure and the Brillouin-based evenness measure was employed. The Brillouin is best used for non-random sampling (Zar, 1996) in comparison to the Shannon-Wiener diversity index. The Brillouin diversity measure H is written as:

$$H = (\log n! - \sum \log f_i!)/n$$

where n is the sample size, and f_i is the number of observations in category i . The evenness measure, J is the relationship of the calculated diversity index to the maximum possible diversity values. The formula for computing the J value is

$$J = H/H_{\max}$$

where H_{\max} is

$$H_{\max} = [\log n! - (k - d) \log c! - d \log (c + 1)!]/n$$

Here, k is the number of categories, c is the integer portion of n/k , and d is the remainder (Zar, 1996).

Modifications on the fossil counts were made with the population data used to determine the diversity of a system. For example, a turtle can produce several shell fragments in the fossil record. Therefore, only limb and skull material from the vertebrate fossils were counted as individuals where articulation of specimens was not present. In the case of lungfish, only the teeth and skull material were counted. Lungfish

have four large teeth that preserve well and make a good substitution for limb counts.

If a species was present but no limb or skull material was available, the population count for that species was listed as one. To determine the top predator of a system, counts of the shed teeth were used. It is assumed that the shed tooth rates for theropods and crocodiles were similar. Therefore, the most abundant tooth type found in each unit identified the top predator.

To understand the community or the faunal relationships within a quarry, a list was generated (Appendix C), showing which species were present at each quarry and where they occur within each stratigraphic horizon (see Table 2 in Results). These data were used to describe various biofacies, which can be added to the main stratigraphic column.

Taphonomy

The taphonomy was described using field observations and physical evidence of the fossil specimens (Appendix C). For vertebrate fossils, the taphonomy of each quarry or locality was entered into five categories using the criteria listed in Table 1. These categories were taken from previous work by Behrensmeyer (1991) with some alterations by the author. To describe the taphonomy of the vertebrate fauna at Como Bluff, two main sets of variables, including the assemblage data and bone modification, were identified for each quarry. Within the assemblage data, references to the average body size, age spectrum, skeletal parts, and bone articulation were recorded. Body size was evaluated because smaller bones react differently to environmental conditions than larger bones and their concentration can be attributed to both biological and fluvial processes

TABLE 1—Taphonomic classification of vertebrate fossil assemblages

Variables Assemblage Data	Classification Codes				
	1	2	3	4	5
Body size Example>	x-small (turtle)	small (<i>Drinker</i>)	medium (camptosaur)	large (allosaur)	x-large (camarasaur)
Age spectrum	young only	75%-25% (young-adult)	50%-50% (young-adult)	25%-75% (young-adult)	adults only
Skeletal parts Bone articulation	unsorted articulated	partially partially articulated	sorted disarticulated & associated	few parts associated & dispersed	only 1 bone isolated & dispersed
Bone Modification					
Breakage	complete	chipped	broken	mult. breaks	fragments
Abrasion	unabraded	some	abraded	much	rounded
Surface marks (punctures, chew, scratches, etc.)	none	hint	present	many	extensive

(Behrensmeyer, 1991). The classification codes for the body size ranges from extra small (x-small) or turtle size to extra large (x-large) or camarasaur size. The age spectrum describes the proportions of juvenile versus adult animals. The five categories or classification codes for the age spectrum is listed as code 1 = all adults, code 2 = 75% adults to 25% juvenile, code 3 = 50% adults and 50% juvenile, code 4 = 25% adults and 75% juvenile, and code 5 = all juvenile. These data can be useful in describing the taphonomic history of a quarry. For example, a wide variety of ages represented in a quarry can be the result of a catastrophic event. If only one age group is present, then attritional mechanisms such as old age or predation may be the cause of mortality. The age of a particular animal was estimated based on its size compared to the known maximum size of the species and other osteological characteristics. The skeletal parts of a quarry can be used to describe how and what degree of movement has occurred after

death of the animal. This is based on the degree of sorting. Where no movement has occurred, there would be no sorting and the skeletal elements would be present in the original anatomical proportions or fully articulated. Partial and sorted skeletal elements may represent fluvial action. Scavenging by large predators is often indicated when only a few skeletal parts of the individual are found. Bone articulation is related to the sorting of skeletal parts in that it describes the degree of postmortem movement. Furthermore, bone articulation can be used to describe exposure time or burial rates. Bone modification describes the taphonomy of an individual bone instead of a quarry. These modifications can be quite diagnostic of a specific process or agent. Breakage of fresh bone usually occurs through trampling or mastication by carnivores. Fluvial processes do not often produce broken or chipped bones unless they have undergone intense weathering prior to the fluvial action. However, some bones can demonstrate fluvial transport through the amount of abrasion that is present. Surface marks can also demonstrate fluvial action. However, they can be also attributed to chewing by carnivores, beetle borings from the Dermestidae or the Histeridae families (Hasiotis et al., 1999), or root action. The classification codes for the bone modifications are based on the degree of breakage, abrasion, and surface marks present. From these taphonomic variables, the original data were quantified through classification codes and a table was produced (Table C.1, Appendix C). The data from this table were entered into the MVSP 4.10 (1998) software program where a principal component analysis was performed and a scatter plot was produced showing, if any, grouping of taphonomic characters to stratigraphic position. Where divisions were present, taphonomic facies were identified and applied to the stratigraphic column.

RESULTS

Stratigraphy

The Morrison Formation at Como Bluff Wyoming is divided into four distinct formal and informal units. From the base of the formation to the top, they are listed as: The Lower Morrison – the Windy Hill Member and Lake Como Member (described here as Unit A), and the Upper Morrison – Talking Rocks Member (described here as Unit B and Unit C). Each of these units shows a change in depositional conditions with a corresponding lithologic and paleoecological system. A stratigraphic column and detailed description of the sections are given (Figure 2 and Appendix D, respectively).

Sundance Formation

The Morrison Formation is bounded on the lower contact by a series of marine sediments known as the Sundance Formation. The uppermost member is the Redwater Shale Member, Oxfordian in age (Imlay, 1952; Pipiringos, 1957). The Redwater Shale is a glauconite rich, gray-green shale with thin beds of sandstone and fossiliferous limestone, interpreted as storm beds by Kocurek and Dott (1983). An XRD scan (Table A.1, Appendix A, sample G-1) shows the presence of dolomite and minor amounts of illite in the shales. The contact with the overlying Windy Hill Member of the Morrison Formation is sharp. This contact has been described as the marker for the J5 unconformity (Pipiringos, 1968; Pipiringos and O'Sullivan, 1978; F. Peterson, 1994). However, there was no evidence of erosion or truncation of the shale beds at the contact, making the J5 unconformity difficult to identify.

Windy Hill Member of the Morrison Formation

The Lower Morrison starts with the Windy Hill Sandstone, previously described as the Member A of the Sundance Formation (Pipiringos, 1957) and redescribed by F. Peterson (1994). It is characterized as a yellow, massive to semi-resistant sandstone approximately 2 meters thick with large scale (>1 m) cross-stratification. Few fossils are present. It consists mainly of calcite-cemented, fine-grained quartz sand with minor amounts of glauconite and other trace minerals. The shales and mudstones immediately above and below the sandstone unit show the presence of dolomite and illite in the XRD scans (Table A.1, Appendix A, samples G-1 and G-4). The Windy Hill Sandstone and part of the shale above are called the Windy Hill Member in the main stratigraphic column (Figure 2).

Unit A of the Morrison Formation

Above the Windy Hill Member is Unit A or the Lake Como Member. This unit consists of a basal tabular limestone bed approximately 1 meter in thickness. It is highly resistant and persistent throughout the study area. Lenticular beds of sandstone (or lithic wacke as described by Boggs, 1995), limestone, and chert in a mottled red and green calcareous mudstone and paleosol follow the basal limestone bed. The dominant clay consists of illite and occasionally an illite/smectite mix. Kaolinite was not found in the Lower Morrison. The paleosols are characterized by variegated red and green mudstone with caliche horizons (Figure 4). These horizons often increase in thickness and textural maturity upwards through the section. They can be distinguished from the limestone

beds by their lack of fossils and by the spherical concretionary shaped components in both hand samples and in thin sections (Figure 5). Also noted in the paleosols was the presence of root traces and/or burrows (Figure 6). The limestone beds are often fossiliferous, containing charophytes, ostracods, gastropods, and plant material (Figure 4). The basal limestone unit also contains dinosaur footprints and medium to large-scale (0.15 to 1 m wide) desiccation cracks (Figure 7). The sandstone units are fine-grained, lenticular to thin tabular beds. Most have rip-up clasts and some lag-type deposits at the base with large-scale (1 m wide) trough cross-stratification structures and mega ripples throughout. Where preserved, the top of these beds contains small-scale hummocky cross strata. In the lower part of Unit A, the resistant sandstone beds have a sharp upper contact and an erosional base. The beds are typically concave up at the base and extend laterally for several tens of meters where they eventually pinch out. In the upper part of Unit A, the beds are more tabular with a flat base and extend laterally up to one square kilometer. Paleocurrent data from trough cross-stratification in the sandstone beds show a southward trend and are listed in Appendix D and illustrated in the main stratigraphic columns (Figure 2). Many of these sands are fossiliferous, containing bone and wood fragments. Petrographic studies (Appendix B) show that they consist of monocrystalline angular quartz grains loosely packed with calcite cement. Chert grains are rare and chalcedony was not found in any of the samples. These beds are typically less than 1 meter thick. Some beds are thicker but appear to be the interfingering or amalgamations of more than one bed. The topmost boundary of Unit A is a final layer of caliche or the "boundary caliche." Beyond this point, typical caliche-rich paleosols are no longer present.



Figure 4—Photos of Unit A showing paleosol and caliche horizons.

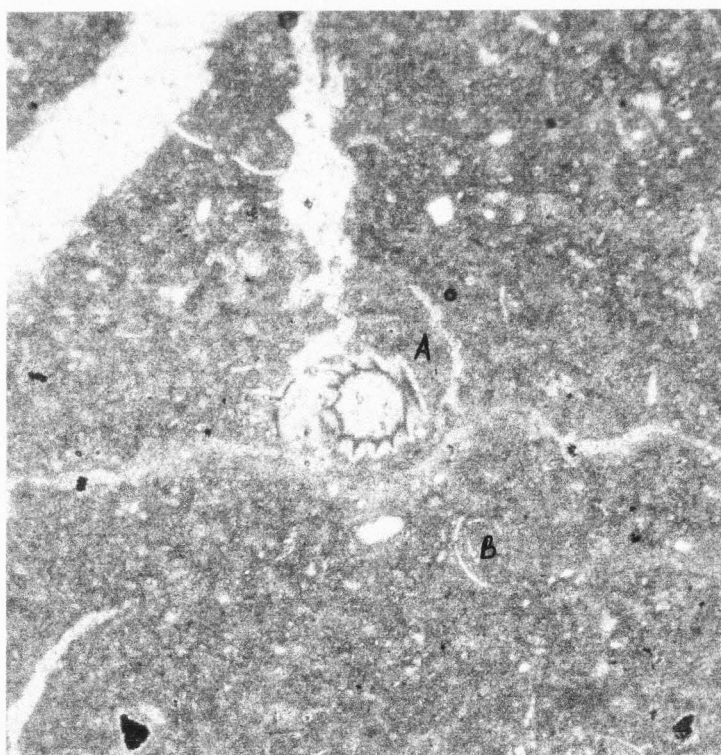


Figure 5—Carbonate textures in Unit A. (Top) Close up view of caliche nodules. (Bottom) Petrographic (4x) view of charophytes, A, and ostracodes, B, in a limestone bed.

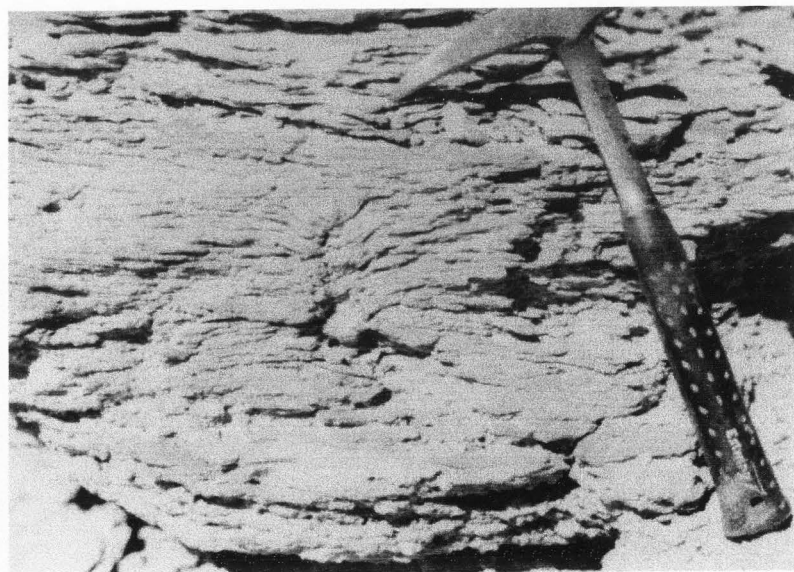


Figure 6—Burrow structures. (Top) Animal burrow or root cast, scale=10cm. (Bottom) Pelecypod escape burrow, hammer =35cm.

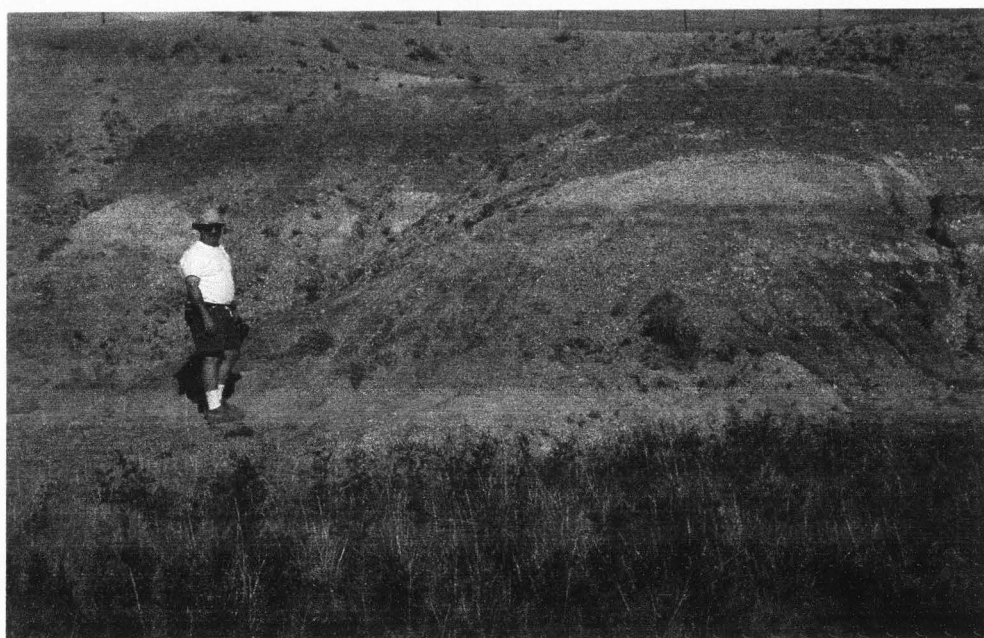
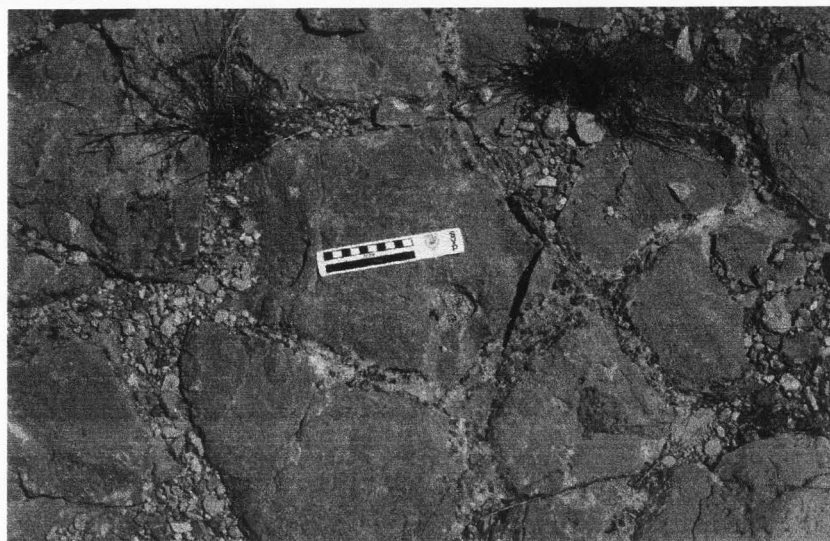


Figure 7—Features found in Unit A. (Top) Medium size mudcracks found in the basal limestone bed. (Bottom) Typical view of Unit A showing paleosols and sandy units.

Unit B of the Morrison Formation

Unit B is part of the Talking Rocks Member and is characterized by smectitic clays, including montmorillonite and beidelite, in light and dark greenish to olive gray calcareous mudstone with thin lenticular beds of limestone and chert. There are no red beds in Unit B. Some sandstone beds are present but less massive than those in Unit A. Petrographic studies show these sandstone beds contain poorly-sorted, quartz-rich, angular grains poorly packed in a calcite-cemented sandstone. The presence of chalcedony and fossils in the form of bone material is common. The limestone beds are generally fossiliferous, containing a different suite of gastropods than the lower beds. Some of these beds change in lithology laterally in the section. One limestone bed containing a large amount of fossil gastropods blends laterally over a few tens of meters into a silica-cemented siltstone and then into a dark chalcedony/chert bed along the outcrop. Furthermore, the frequency of these chert beds increases in Unit B, where only one bed was found in Unit A.

Paleocurrent was difficult to determine due to the lack of sandstone beds with well-preserved cross stratification. Inferences to the paleocurrent were made using rib bone orientations from one of the larger quarries as illustrated in the main stratigraphic column (Figure 2).

Unit C of the Morrison Formation

Unit C was described by Allen (2000) as the topmost part of the Talking Rocks Member, but is distinct enough to be treated as a separate informal unit. The transition

from Unit B to Unit C is gradational and based on the fossil assemblages and subtle changes in lithology. Here, the clays continue to be smectite rich. The mudstone is non-calcareous and generally darker, black in some cases. One small lens of weathered volcanic ash was found in Unit C. Limestone is rare and only found near the base of the unit. Calcite nodules were also found throughout the study area at the base of Unit C. They have a radial, coarsely crystalline structure and vary in size from 3 cm to 15 cm (Figure 8). Some non-, to mildly-resistant thin lenses of mudclast conglomerates and chert beds can be found. The conglomerates contain an increased amount of fossil bone fragments as well as other trace and unidentified material as compared to other sandstone and conglomerate beds in the lower units. Clasts of chalcedony were also common in these beds. Most of the conglomerates occur at the lower half of Unit C. A thin and persistent green, quartz-cemented siltstone occurs throughout the area and is used as the marker bed between Units B and C. Throughout Unit C other lenticular dark yellowish-brown to a creamy opaque chert beds 1 cm to 1 m thick are present. Skeletal remains of large dinosaurs are rare and smaller animals including many Cretaceous-like vertebrates including dinosaurs, turtles, and mammals are more common in Unit C than in the previous units.

Paleocurrent data were obtained from orientations of shed teeth of *Goniopholus* as illustrated in a rose diagram in the main stratigraphic column (Figure 2). The orientations of the teeth also show a southward trend similar to current data found in Units A and B. However, these data were very localized and may not represent the current direction of the whole unit.

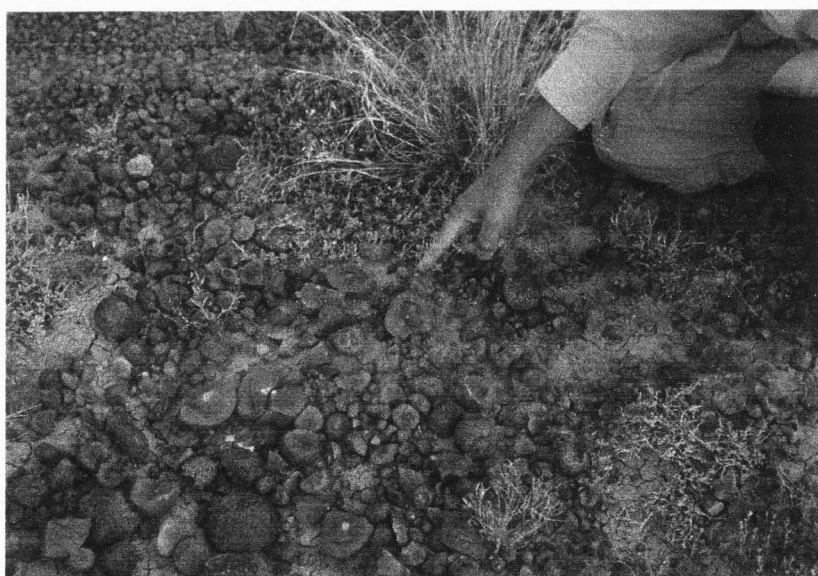


Figure 8—Unit C. (Top) View of “Breakfast Bench.” Claw Quarry 3c and WDIS volunteer on left side of outcrop. (Bottom) Radial, coarsely crystalline calcite nodules found only at the base of Unit C.

On top of Unit C in some areas is a second clay change. In this zone, the dominant clay is kaolinite. This clay type is only found in association with a brownish silty shale containing plant, wood and coal fragments. Although it appears isolated, this zone may indicate formation boundary and will be discussed in more detail later in the document.

Cloverly Formation

The upper contact of the Morrison with the Cloverly Formation is placed at the base of a massive yellow conglomerate that caps the outcrop and main ridge at Como Bluff. The thickness of this bed is variable from a few meters to tens of meters thick. However, since this bed caps the Como Bluff outcrops, the true thickness is difficult to determine due to weathering. This bed has an erosional basal contact overlying the Morrison mudstone and shale beds. It consists of poorly sorted, sub-rounded chert clasts in a sandy matrix. Large scale cross beds are present. This unit extends laterally throughout most of Wyoming.

X-Ray Diffraction Analysis

Ninety-three samples from the mudstone and shale samples collected at Como Bluff were suitable for X-ray diffraction. Seven of these samples did not show any measurable amounts of the three major clay types including smectite, kaolinite and illite. All samples show the presence of quartz. Calcite and dolomite were also found in several of the ninety-three samples. Illite and illite/smectite clays were restricted to samples taken from the lower part of the Morrison Formation where paleosols and variegated

mudstones are present. Smectite, the most dominant clay, was found primarily in the upper half of the formation. In some cases, beidelite and montmorillonite of the smectite family were identified. Kaolinite, the least common clay mineral, was only found at the very top of the stratigraphic columns. Results of the X-ray diffraction analysis can be found in Table A.1 (Appendix A).

Petrographic Analysis

Only 10 samples from the sandstones and conglomerates from Como Bluff were resistant enough to be collected and cut into thin sections for petrographic analysis. Most of these had to be impregnated with epoxy resin before sectioning. Six of these sections were sent to Spectrum Petrographics to stain the feldspars for ease of identification. In Unit A, two samples were point-counted. Sample K-12 is from a splay-like sheet sand and contains 97% quartz of the QFL total. Sample J-9 is from a more typical channel-like sandstone bed and is composed of 67% quartz. Most of the quartz in both samples is monocrystalline and non-undulose. Chalcedony was not found in the two samples. Feldspars make up less than 1% of the QFL total. Unit B had four samples that were point-counted. All of these samples are found near the top of the unit. Again, quartz is the dominant mineral, ranging from 72% in the conglomerates to 91% in the fine grain sandstone. Although most of the quartz grains are monocrystalline, polycrystalline and chalcedony quartzose grains are present. Two samples have less than 1% feldspar. One sample, C-3, contained the highest amount of feldspar (8%, most of which is plagioclase) in all the ten samples. Unit C contains four samples that were point-counted. An increase in lithic grains is noticeable and ranges from 12% to 46% of the QFL total.

Fossil fragments, including bone, teeth, and fish spines, are more common in Unit C than in any other unit (Figure 9). Chalcedony is present in Unit C and some of the quartz grains contained inclusions. Most of the grains in all 10 samples are angular. In some samples, the non-undulose monocrystalline quartz grains are subrounded. Matrix and other non-QFL grains make up 15% to 59% of the total counts. Results and description of the ten samples are listed in Appendix B and plotted on a QFL diagram (Figure B.1).

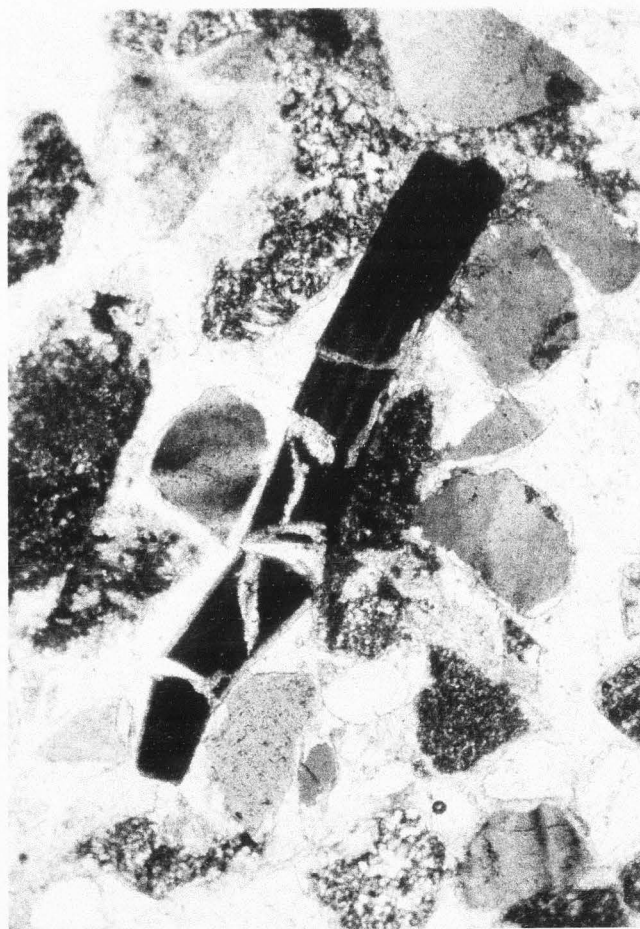


Figure 9—Petrographic (10x) view of sample AARG in Unit C. Center dark object is a vertebrate fossil, possibly a fish spine.

Paleoecology

Variations in the paleoecology of the Morrison Formation were found and appear to follow the same stratigraphic boundaries used to mark the individual members previously described. The megavertebrates appear to be similar to those found in other Morrison localities within the Western Interior (Turner and Peterson, 1999). Many of the microvertebrates appear to be endemic to the Como Bluff region. Both mega and microvertebrates, however, seem to be autochthonous, providing excellent paleoecological information. This was interpreted through taphonomic studies and faunal relationships coupled with the environmental interpretations from the previous stratigraphic work (F. Peterson, 1994; Allen, 2000). Stratigraphic ranges of the vertebrates found at Como Bluff can be seen in Table 2.

Taphonomy

Using the taphonomic criteria listed in the methods portion of this study (Table 1), scores from each major quarry (Table C.1) were entered into a principal component analysis and a scatter plot showing axis 1 vs. axis 2 was produced showing minor groupings between the upper and lower Morrison at Como Bluff (Figure 10). Groupings along axis 3 were virtually non-existent and thus not shown in Figure 10. Because the groupings are not clearly defined, a very basic taphofacies model was developed and applied to the main section (Figure 2). Unit A typically contains quarries with single or a low number of individuals. These individuals are generally larger, adult-sized animals

preserved in two types of settings. Only one "micro site," containing several small vertebrates, was found. Data from this site was not available at this time, as the

TABLE 2—Stratigraphic ranges of vertebrate fossils found in the Morrison Formation at Como Bluff.

Species	Stratigraphic Units			
	Windy Hill	Unit A	Unit B	Unit C
<u>Theropods</u>				
<i>Allosaurus</i>	1—4a—2b—10c—3c—1			
Megalosaurids		1—2b—10c—3c—1		
<i>Edmarka rex</i>		1—2b—?		
<i>Ceratosaurus</i>				?—10c—3c—1
<i>Coelurus</i>			1—Q9—13c—3c—1	
Dromiosaurids				1—3c—
<u>Sauropods</u>				
<i>Apatosaurus</i>	?—2b—Q4—?			
<i>A. yahnahpin</i>	1—4a—1			
<i>Camarasaurus</i>	1—12a—9a—2b—Q4—14c—			
<i>Diplodocus</i>	?—4a—2b—3c—			
<i>Brachiosaurus</i>		?—2b—?		
<u>Ornithopods</u>				
<i>Drinker nisti</i>				1—10c—6c—3c—1
<i>Othneilia</i>	1—1a—?			1—3c—
<i>Stegosaurus</i>	1—9a—2b—Q9—Q4—1			
<i>Camptosaurus</i>	1—9a—?	Q9		
<i>Driosaur</i>	1—17a—4a—?			
<u>Other vertebrates</u>				
<i>Goniopholis</i>	1—1a—Q9—3c—			
<i>Beainid</i>		?		1—10c—7c—3c—
New turtle genus	1—1a—?			
<i>Gliptops</i>	1—Q13—Q9—3c—			
<i>Ceratodus robustus</i>				1—7c—3c—1
<i>C. fossanovum</i>			1—Q9—13c, 7c—3c—1	
<i>C. guntheri</i>			—Q9—?	
<i>C. sp #1</i>				?—3c—1
<i>C. sp #2</i>				?—7c—3c—1
Mammals	?—1a—?		?—Q9—13c—3c—	
Sphenodontid			1—2b—13c—3c—	
Creastodine			1—Q9—3c—	

discovery was made by the Wyoming Dinosaur International Society just prior to the writing of this document (Bakker, personal communication, 2001). In most of the sandstone beds, bones are often partially articulated. In the mudstone facies, fossils are disarticulated and poorly preserved where as many of the bones are often encased in concretions due to the processes in soil maturation (Retallack, 1997).

Unit B is similar in its taphonomy to Unit A. Again, generally-large animals are represented in most quarries. The difference between the taphonomy of Unit B and Unit A is the lack of articulated specimens. Most fossils found in Unit B are highly disarticulated and often isolated. Concentrations of bones do not appear to be produced by fluvial action as most quarries exist in a fine-grained mudstone facies. However, the attitudes of some of the bones do show an orientation preference (Appendix D and illustrated in Figure 2).

Unit C contains a distinctive taphonomy as compared to units A and B. Most of the disarticulated specimens can be found within small, mildly-resistant conglomerates. Many of the bones from the micro vertebrate fauna that are found within the conglomerates are delicate and, although often broken, probably due to trampling or mastication (Behrensmeyer, 1991), show a relatively low degree of travel. Almost all of the larger dinosaur bones found within these conglomerate lenses are highly polished into round pebbles, showing a high degree of travel of partially fossilized material. Unit C also contains a few articulated specimens as well. These specimens are small vertebrates known as *Drinker nisti*. In these cases, the vertebrates are found within the mudstone matrix. Several specimens may be found together in one small (1 cubic meter) quarry.

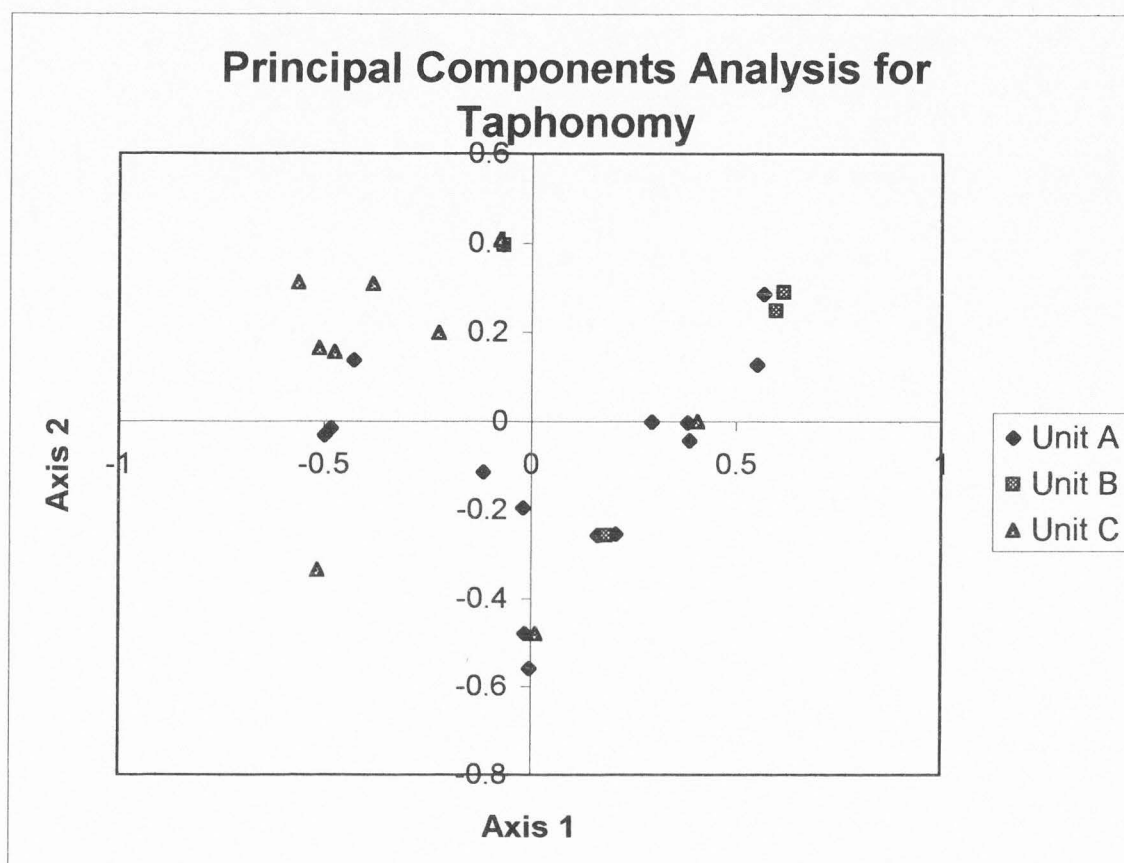


FIGURE 10—Scatter plot showing the results of the principal components analysis for the taphonomy scores within each unit. Analyzing 7 variables and 27 cases. Tolerance of eigenanalysis set at 1E-10. Axis 3 is not shown.

Here, little or no transportation of the animal after death is evident based on the high degree of articulation and lack of bone modification.

Faunal Relationships

Appendix C and Table 2 show the faunal relationships that exist at Como Bluff. Most taxa were identified to the genus level. Smaller vertebrates, including lungfish and mammals, could be identified to species. Many taxa such as *Allosaurus*, *Camarasaurus*,

Diplodocus, and *Goniopholis* were present throughout the entire section. Ornithopods seem to be more restricted to specific units.

Unit A is dominated by large sauropods including *Apatosaurus yahnii*. The top dinosaur predator appears to be *Allosaurus* (Table 3), based on the shed tooth count. Other common dinosaurs include *Stegosaurus*, *Camptosaurus*, and *Dryosaurus*. Invertebrates that can be identified include gastropods, pelecypods, and ostracodes. Tidwell (personal communications) identified many of the plant specimens as *Equisetum*, *Brachyphyllum*, and other fern-like species. Only one lungfish fragment was found in Unit A. Throughout Unit A, the diversity evenness value of the vertebrates tends to be lower than in the other units (Table 4).

Unit B has a slight change in the faunal list. Sauropods are still dominant members of the dinosaur species with *Camarasaurus* being the most common. *Apatosaurus yahnii* is replaced by *A. excelsus*. Megalosaurids and *Allosaurus* are common predators with *Allosaurus* being the top predator. *Stegosaurus* is still present, but more rare than in Unit A. Invertebrates include gastropods, ostracodes, and insect larval chambers. Some of the gastropod specimens are quite large and exceed those previously described by Yen (1952). Lungfish were present, but are represented by only two species, *Ceratodus fossinovum* and *C. guntheri*.

TABLE 3—Carnivore shed tooth counts

Unit	Allosaur	Megalosaur	<i>Ceratosauros</i>	<i>Goniopholis</i>	Other
A	4	0	0	9	0
B	45	0	1	0	0
C	15	12	24	300+	11

TABLE 4—Diversity and evenness values of vertebrates for quarries with computable data, Brillouin's method, log base 10

Quarry #	H-Index	J -Evenness	# of Species
1a	0.538	1.000	7
2b	0.629	0.733	9
3c	0.878	0.775	21
4a	0.345	1.000	4
5a	0.151	1.000	2
7c	0.418	0.943	5
8c	0.270	1.000	3
9a	0.659	0.978	10
10c	0.529	1.000	7
13c	0.678	0.800	12
14c	0.259	1.000	3
15c	0.151	1.000	2
20c	0.366	0.860	4
21a	0.151	1.000	2
24c	0.151	1.000	2
25a	0.151	1.000	2

Unit C shows an abrupt change in the faunal list. Here, most of the specimens are smaller with a higher evenness value (J) (Zar, 1996) than in Unit B and almost equal to Unit A. The diversity index H of Unit C is greater than in Unit A but smaller than in Unit B. However, Unit B had only one computable sample, which may not accurately describe the diversity. Large dinosaurs such as the sauropods decrease in the fossil record at Como Bluff. Herbivores are dominated by the smaller hypsolophodontids such as *Drinker nisti* and *Othnielia*. *Drinker* is the most common dinosaur in Unit C. Three theropods are common predators, including *Allosaurus*, Megalosaurids, and *Ceratosaurus*, with *Ceratosaurus* being the most dominant therian. *Goniopholis* is probably the top predator overall. Lungfish include four species: *Ceratodus robustus*, *C.*

fossanovum, and two undescribed species. Furthermore, evidence of Cretaceous animals including dinosaurs, mammals, and turtles is present.

DISCUSSION

Based on the stratigraphy and the paleontological data found in the study area, a model of the paleoenvironment and the associated ecological system can be created. Major changes in lithology occur between the Upper Morrison and the Lower Morrison Formation. Major paleontological changes in the faunal composition appear to occur between Unit B and Unit C of the Upper Morrison.

Paleoenvironmental Reconstruction

Windy Hill Formation

The Windy Hill Member clearly represents a marine or near shore marine environment. The well sorted sandstone with the characteristics previously described indicates that it may be reworked eolianite. Eolianite is well known in the Morrison and other Jurassic Formations throughout the Western Interior (Kocurek and Dott, 1983; F. Peterson, 1994). The sandstone bed and the shales immediately above and below the sandstone contain glauconite and dolomite suggesting a marine influence. Dolomite can be diagenetically produced. However, since no other members of the Morrison Formation at Como Bluff contain dolomite, it is believed that the dolomite was produced prior to the deposition of the other members and is not diagenetic.

Unit A

Using the evidence described in the Results portion of this document, Unit A

can be interpreted as being produced by a fluvial and floodplain system in a seasonally arid or subhumid environment. This is supported by the caliche-rich, red-mottled paleosols with small point bar channel and splay-like sandstone beds present in Unit A. Nodular caliche is often associated with arid land paleosols (Retallack, 1998), suggesting that the paleosols in Unit A at Como Bluff, were produced under similar conditions. Paleosols in calcareous red beds are described as being similar to modern soils produced in large continental interiors and on the downwind side of mountain ranges (Retallack, 1998). The calcareous nodules or caliche can be associated with many different soil profiles. In aridisols, these nodules are usually found within 1 m of the surface (Weaver, 1989). This also appears to be true with the caliche zones at Como Bluff as indicated by the root casts, burrows and clay types present. The main clay type found within the caliche zones is illite. Illite has been described as common within the A horizon of aridisols (Weaver, 1989), which should put the caliche zone near the surface. It is believed that pedogenic illite is formed in aridic soils as the result of the weathering of smectite, in the presence of K and/or K-minerals, within a wet and dry environment (Weaver, 1989). However, illite is relatively resistant to weathering and the illite in the A horizon is probably "inherited illite" through river transportation. Although the paleosols at Como Bluff best resemble aridisols, the influences of erosion, compaction and other diagenetic processes, which can affect the clay type, color and thickness of the paleosol horizon must be taken into account. Therefore, it may not be possible to clearly identify which type of arid soil profile is present at Como Bluff.

As noted previously, the caliche beds increase in thickness upward through the section. As suggested by Reeves (1976), the maturation and thickness of a caliche bed

can be the result of exposure time. Therefore, this increase in caliche thickness may suggest a gradual decrease in sedimentation rates throughout Unit A.

Sandstone beds in the lower half of Unit A appear to be typical fluvial or channel-like sand deposits as described by Boggs (1995). This is supported by the bed geometry, cross-stratification, rip-up clasts, and, in some cases, lag-type deposits found at the base of each sandstone unit. In the upper part of Unit A, the sandstone beds are more tabular and resemble crevasse splay sands. The large-scale trough cross-stratification followed by the hummocky cross strata shows a vertical decrease in stream velocity (Figure 11). These tabular beds do not contain any burrows or living chambers, such as those found in the lower channel-like beds with the exception of escape burrows (Figure 6). Furthermore, the taphonomy, including the partially articulated large saurian specimens associated with these beds, suggests that many are single flood events, also indicative of splay sands. Another possible origin for the sheet sandstone beds would be the lateral coalescence of lenticular channel bodies (Collinson, 1978). However, the lack of erosional contacts between individual channels suggests that this is not the case. Another theory supporting the arid/subhumid seasonal environment can be found within the paleontological data based on dinosaurian morphology. Many of the dinosaur species are animals with a small foot-to-body size ratio. Bakker (1996) suggested that these animals would prefer a hard substrate. Unit A also includes one large and several smaller lacustrine limestone beds. Many of these are highly fossiliferous with charophytes, ostracodes, mollusks, vascular plants, and algal mats, indicating that the water was oxygenated and probably basic.



FIGURE 11—Sandstone beds in Unit A. (Top) Typical trough cross-stratification ~1 m wide. (Bottom) Side view of trough cross-stratification at the base with hummocky cross beds on top. Hammer=35cm long.

Unit B

The lithology in Unit B suggests that either an environmental change and/or a change in the source material from tectonic activity may have occurred. The lack of caliche and the red and green mottled paleosols may indicate that the floodplain was no longer subjected to the same oxidizing seasonal wet and dry environment as described for Unit A. The darker, gray-green smectitic mudstone beds appear to be produced in quiet and relatively undisturbed reducing environments. The formation of smectite favors low relief or poorly drained soils, low rainfall, and/or low water flux along with low temperature (Weaver, 1989). It "can form by the alteration (transformation) of volcanic glass, feldspars, micas, various FeMg silicates and the silication of detrital physils" (Weaver, 1989). However, montmorillonitic soils, such as vertisols, require a distinct wet and dry season. In this case, the change in clay type may be the result of source material instead of a change in climate. The lack of clean ash beds suggests that the volcanic material was not airborne such as an ash fall. If the montmorillonite was formed by the alteration of volcanic glass, then it would be considered, in part, detrital in origin. The chert beds present in Unit B are similar to the "magadi-type" cherts from the type Morrison Locality as described by Dunagan (1998). The formation of magadi-type cherts is associated with the precipitation and subsequent alteration of Na-silicates to a silica gel, which dehydrates to chert in a semiarid, high alkaline environment (Carozzi, 1993). The presence of the magadi-type chert in Unit B may explain the lack of good ash beds in that the ash may have been altered to produce the cherts. Again, the presence of both limestone and chert beds in Unit B would indicate that seasonal wet and dry seasons still

existed in Unit B and that the change in lithology between the two units is probably dominated by a change in source material.

Unit C

Unit C is lithologically similar to Unit B, but subtle changes may suggest a slightly different environment. Although limestone beds are uncommon, the darker finely laminated mudstones suggest that small ponds or lakes were still present at Como Bluff. These detrital lacustrine sediments show little sedimentary influence by carbonate producing organisms. The lack of these organisms may be the result of poor water quality such as low oxygen levels or pH incompatibility. Most of the dinosaurs present have a large foot to body ratio, suggesting a softer substrate, similar to a poorly drained back swamp environment. The kaolinite zone with the coaly shale beds also indicates a less arid, swamp-like environment. Unit C also has fewer resistant beds, most of which are chert. Some of these chert beds are similar to the magadi-type cherts found in Unit B, thus indicating occasional semiarid to subhumid events. Some of these beds show relic algal mats and root casts. The coarser clastic material is poorly sorted and high in lithics and chert pebbles. Evidence indicates that little transportation of many of the smaller and more delicate fossils has occurred in the mudclast conglomerates. These delicate smaller vertebrate fossils are well preserved. Based on puncture marks found on some of the bones and by lack of apparent abrasion, breakage may be the result of mastication by predators or trampling. This assumption is based on the works of Behrensmeyer (1991, p. 308), who said: "Fresh bones have high tensile strength, and breaking them takes considerable force, such as that exerted by carnivore mastication, stone-tool use or

trampling. . . . No breakage occurred within an experimental sample of over 100 . . . cow, horse, and sheep bones transported by natural rivers for several kilometers in sand and gravel-bed streams over periods up to 12 years." There are also highly-abraded, rounded pebbles made from large dinosaur bone material within the conglomerate. These two types of bone preservations contradict each other in the interpretation of the depositional environment. It is suggested that the large, highly-abraded bone material is due to the reworking of lower sediments such as those of Unit B. The roundness of these bones indicates that the bone may have been previously or at least partially fossilized. Bone preservation in Unit B is often the result of permineralization by silica, making them quite resistant to weathering, whereas the bones in Unit C are not often replaced with silica and, thus, not as resistant to weathering.

Cloverly Formation

Overlying the mudstones of Unit C is a thick massive yellow conglomerate of the Cloverly Formation. The variable thickness of Unit C and the characteristics of the contact suggest that the Cloverly lies unconformably on the Morrison and possibly the position of the K1 unconformity. The contact between the Morrison Formation and the overlying Cloverly Formation has been placed at the base of the massive conglomerate, which is consistent with the marked boundaries placed by other workers in other areas (Meyers et al., 1992; Schmude and Weege, 1996; Dunagan, 1998; Peterson and Turner, 1998; Turner and Peterson, 1999; Allen, 2000).

Jurassic/Cretaceous Boundary and the Age of the Morrison Formation

The Jurassic/Cretaceous or J/K contact in the Western Interior has been the subject of numerous debates (Thomas, 1962). The position of this contact is important to many researchers who date the Morrison Formation as being Jurassic or Cretaceous. This contact has been identified in most areas through palynomorph (Litwin et al., 1998), charophyte and ostracode (Schudak et al., 1998), and magnetostratigraphic analysis (Steiner et al., 1994) studies. In most of the areas studied, this contact has been placed at the Morrison/Cloverly contact, thus making the Morrison Formation Jurassic in age.

However, the Morrison/Cloverly boundary has also been subject to debate (Haun and Barlow, 1962; Peck and Craig, 1962; Peterson and Turner, 1998). This is illustrated in several publications including the Geologic Map of Wyoming where the Morrison and the Cloverly are listed as undivided in many areas (Thomas, 1962; Love and Christiansen, 1985). Where the two formations are divided, the Cloverly has been described as having a massive basal conglomerate lying unconformably on top of Morrison mudstone and shale beds. At the type section, Peterson and Turner (1998) list the contact at the base of the Lytle Formation, which is also a conglomerate lying unconformably on top of nonresistant mudstone and paleosols. This is a logical placement of the Morrison/Cloverly contact if formation status is based primarily on "lithologic character" as suggested by the International Stratigraphic Guide (Salvador, 1994).

At Como Bluff, the Cloverly conglomerates are present and appear to lay unconformably on nonresistant mudstone and shale beds. However, in some of the

stratigraphic sections measured at Como Bluff (sections Center, A, B, and C in pocket), a zone of coaly shale and mudstone containing Cretaceous-like plant material is present and was described as being Cretaceous in age by F. Peterson (personal communication, 1996). This zone is distinguished from the lower mudstone units through the presence of kaolinite. Kaolinite has not been found anywhere else in the section, but has been described from the lower units at the type locality. Hooper (1962) mentioned that kaolinite was present in the Lakota Conglomerate (basal member of the Cloverly Group) in the Casper Arch area approximately 90 miles north of Como Bluff. Although shales were described as a constituent of the Cloverly Formation, they were not described as preceding the basal conglomerates. If this second "clay change" is significant, then the zone may be considered part of the Cloverly, leaving the Morrison Formation Jurassic in age. However, if the pattern used by previous authors (Meyers et al., 1992; Schmude and Weege, 1996; Dunagan, 1998; Peterson and Turner, 1998; Tuner and Peterson, 1999; Allen, 2000) was followed, then this zone should be placed within the Morrison Formation, making the Morrison, in part, Cretaceous in age. This assumption should not nullify previous research pertaining to the age of the Morrison. This zone is not always present in the Como Bluff region and may even be restricted to the research area and therefore, not be representative of other Morrison localities. Therefore, without data from this zone, it would be difficult to clearly identify the age of the Morrison Formation. It is suggested by this author that this zone be placed within the Morrison Formation until a more detailed description of the lithologic characteristics used to discriminate the beds of the Cloverly Formation from those of the Morrison

Formation is obtained. This placement would place the J/K boundary within the upper beds of the Morrison Formation and not at the Morrison/Cloverly boundary.

Paleoecological Interpretation

Windy Hill Member

In the lower Morrison, the Windy Hill Member is deficient in paleontological data. The only evidence of a vertebrate fauna comes from the report of a possible pterodactyl track (Lockley et al., 1986) and a few pyritized coprolites. Pterosaur tracks are well known from other Windy Hill localities farther north in Wyoming (Logue, 1977). These tracks suggest that the pterosaurs were well adapted to a near shore marine environment. If pterosaur tracks are present at Como Bluff, then the paleoecology of the Windy Hill would consist of a near shore marine faunal assemblage similar to other localities. The presence of glauconite does suggest a strong marine influence on the sediments. Therefore, the Windy Hill Member may not have been subaerially exposed long enough to support a terrestrial vertebrate fauna. Invertebrate material, mostly marine, was found in the Windy Hill Member north of Como Bluff at the Alcova Lake area. However, no such material has been described from the Como Bluff region.

Unit A

Unit A probably has the most stereotypical display of Jurassic dinosaur assemblages including: *Apatosaurus yahnahpin* (also known as *Eobrontosaurus yahnahpin*, Bakker, 1998), *Camarasaurus*, *Stegosaurus*, and *Allosaurus*. The

iguanodontid-like animal *Camptosaurus* is abundant at Como Bluff, but appears to be restricted to Unit A. Only one possible exception was found, with an unknown species of a camptosaur listed from Reed's Quarry 9, located in Unit B. Most of the sauropod dinosaurs may be characterized as animals capable of large migrational patterns and may have moved in and out of the Como Bluff area during favorable seasonal events. Tracks in the lower limestone show that large groups of sauropods moved together unidirectionally (Southwell et al., 1996). Among the smaller, non-migrational animals, the newly discovered primitive turtle was very small compared to *Dorsetochelys buzzops*, family Baenidae, from the Breakfast Bench fauna of Unit C.

Taphonomic indicators show that many animals died sometime near the flooding events, as partially articulated carcasses of all age groups were preserved in the splay-like sandstone beds. The Bertha site (4a) demonstrates a single catastrophic occurrence where the animal may have been mired during a flooding event and subsequently died (Filla and Redman, 1994). A second type of taphonomic setting found in Unit A is the floodplain. The few carcasses found on the floodplains show extensive scavenging. These sites often consist of single individuals with very little articulation and a high degree of tooth scratches. The degree of articulation appears to be a function of exposure time (or sedimentation rate) after death, as described by Hill and Behrensmeyer (1984).

The aquatic fauna is represented by gastropods, including *Lymnaea morrisonensis* and *Amplovalvate cyclostoma*, unioid pelecypods, ostracodes, and *Glyptops*. There is very little evidence of *Goniopholis* (only shed teeth) and no direct evidence of amioid and lungfish. However, according to Kirkland (1998), unioids are dependent on amioid fish to complete their growth cycle. If this were true during Jurassic time, then fish should be

present. This does not hold true for lungfish. The lack of lungfish may suggest that the lake systems were not suitable for a healthy lungfish population.

Plant remains are consistent with previous descriptions of Morrison flora, consisting of open forests composed of conifers and cycads with a mingling of ferns as understory (Tidwell et al., 1972).

Unit B

The fauna of Unit B is similar to Unit A, but exhibits changes at the species level. Sauropods are still abundant. *Apatosaurus yahnahpin* is replaced by *A. excelsus*. Allosaurs are still the top predator. Also, the megalosaur *Edmarka rex* is now present in the area. Taphonomic data show that few animals were buried during catastrophic events. Most sites contain one or a few isolated bones. A few larger quarries, such as the Nail Quarry (site WDIS 2b), contain several animals. There is little to no articulation, but many of the bones are associated. Based on shed teeth counts, *Allosaurus* was probably the only scavenger/predator at the Nail quarry. The limestone beds in Unit B are thinner and less persistent than in Unit A. They contain many similar fossil types, however, and changes between species and genera may be noted. The gastropod *Amplovalvata cyclostoma* in Unit A seems to be replaced with *A. scabrida* in Unit B. The dominant gastropod was *Viviparus morrisonensis*, which is common in, and limited to, Unit B. Some specimens of the *V. morrisonensis* are of an unusually large size and much larger than those previously described from the Morrison Formation by Yen (1952). Viviparids are pulmonates and respire with atmospheric oxygen (Hartman, 1988), enabling them to survive in a less-oxygenated lacustrine system. Lungfish were found in this unit. The

species seem to be limited to *Ceratodus fossanovum* and *C. guntheri*, which were found at Marsh's Quarry 9 and the Blue Nimbus Quarry (WDIS 20c). All are small individuals compared to some lungfish specimens in Unit C.

Unit C

Unit C is best interpreted through the fossil assemblages present. Most of the vertebrates are considered aquatic, including lungfish, amioids, crocodiles, and turtles. Other vertebrates can easily be interpreted as bank dwellers, such as small mammals and short-toothed pterodactyls. This study found tracks of pterodactyls in a mudstone facies of the Morrison Formation north of Como Bluff. Track patterns show feeding-like behavior along a mud bank of a fluvial system (unpublished data by author). The high ratio of shed *Goniopholis* teeth to shed theropod dinosaur teeth is an indicator of the proximity of aquatic habitats (Bakker, 1997). The dinosaurs of Unit C tend to have a larger foot to body size ratio than those in the lower members and may be better suited to a softer substrate (Bakker, 1996). *Ceratosaurus* replaces *Allosaurus* as the dominant theropod. *Ceratosaurus* is probably better equipped as an ambush predator and/or swimmer with its shorter legs and stronger crocodilian-like tail, making it well suited for a swamp-like environment. The mammal populations that exist in Unit C include new families of multituberculates (Bakker, 1998). As mentioned previously, many of the articulated vertebrate skeletons found in Unit C belong to a species known as *Drinker nisti*. Small quarries (approximately 1 meter square) may contain one to as many as 13 articulated individuals, with all age groups represented. It was suggested by Bakker (personal communication, 1994) that these small blocks could be the remains of burrows

in which the animal or animals died, possibly due to flooding events or disease. The burrow hypothesis would explain the lack of scavenging and the accumulation of so many individuals. The high number of aquatic animals suggests that the environment had many small lakes or slow river systems. The presence of four lungfish species with most age groups present suggests that these systems were the preferred habitat of lungfish. One lungfish species, *Ceratodus robustus*, grew to enormous size, possibly exceeding 3 meters in length. Few to no mollusks were found, indicating that the waters may have been acidic and/or low in oxygen. However, this habitat could support other animals such as turtles and crocodiles that do not depend on the oxygen content of the water (Kaznyshkin et al., 1990). As mentioned above, evidence of some Cretaceous-like animals was found within Unit C. Troodontid-like teeth and a claw believed to be from a dromiosaurid were found within the Claw Quarry, well below the Morrison/Cloverly boundary. Both of these animals are known from the late Cretaceous Period (Charig, 1973). Furthermore, fragments of cretaceous-like turtles and mammals were also found. However, at the time of this report, there was not enough material for a clear identification.

SUMMARY

The Morrison Formation shows a clear change in the paleoenvironment and corresponding paleoecology from the base to the top of the section. The Lower Morrison is characterized as a seasonally wet and dry, well-drained fluvial environment as represented by the illitic- and caliche-rich paleosols and sandstone beds. The paleoecology can be described as containing typical large dinosaur fauna capable of large migrational patterns and of the type that prefer a firm substrate. The micro vertebrate fauna is aquatic, including smaller and more primitive turtles, mollusks, and crocodiles. Rare, but present animals include mammals and small ornithopods.

The Upper Morrison shows a gradual change from a seasonal wet and dry climate to a more humid lacustrine to swamp-like environment based on the darkening of sediments, an increase of carbonaceous plant material, and the abundance of aquatic fauna throughout the unit. Smectite-rich mudstones suggest a change in conditions, either in the source rock or in the climate. Large saurian dinosaurs decrease in number as well as change in species within genera. Crocodiles, turtles, and lungfish, some of which are endemic, dominate the aquatic fauna in the uppermost bed, also known as the Breakfast Bench fauna. The most common dinosaur is the small ornithopod *Drinker nesti*. *Ceratosaurus* replaced *Allosaurus* as the top theropod. In addition, an increase in Cretaceous-like dinosaurs, turtles, and mammals is also present. The upper contact between the Morrison Formation and the overlying Cloverly Formation is placed at the base of the Cloverly conglomerate. In the Como Bluff area, a second change in clay type, from smectite to kaolinite, is present near the top and could be used to place the J/K

boundary. In areas where kaolinite and/or plant material are not present, the J/K boundary can be placed at the base of the Cloverly conglomerates.

Stratigraphic changes in both the sedimentology and paleoecology are present at Como Bluff. However, these changes do not necessarily correspond to changes found at the type locality and other well-described localities of the Morrison Formation.

Therefore, the criteria for unit identification listed above may be restricted to the Como Bluff region. The units described in this project complement the member identification for the Morrison Formation of Wyoming, recently published by Allen (2000). If the recent publication is accepted by the geological community, the units can be reassigned as members and listed as the Windy Hill Member, Lake Como Member (Unit A), Talking Rocks Member (Unit B and C) of the Morrison Formation.

Exclusive of the kaolinitic zone, the age of the Morrison Formation at the Como Bluff region appears to be similar to the ages described for other Morrison localities in the Western Interior, which is restricted to the Late Jurassic Era and the Kimmeridgian and early Tithonian Stages. This is based on $^{40}\text{Ar}/^{39}\text{Ar}$ isotopic dates as well as other paleontological dating techniques (Turner and Peterson, 1999) used by other workers. If these dates are correct, then many vertebrate species found in the Breakfast Bench, as previously described and thought to be restricted to the Cretaceous Period, originated in the late Jurassic.

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APPENDICES

Appendix A. X-Ray Diffraction Analyses

TABLE A.1—Results of X-ray diffraction analyses of samples from Como Bluff.
Absence of mineral is indicated by 0; presence, by +, and trace by t, m=montmorillinite
and b=beidelite.

Sample number	Smectite	Illite	Kaolinite	Other
A-20	0	0	0	t-Halloysite 10A
A-21	t	0	0	
A-24	0	0	0	
A-28	t	0	+	
A-29	t	0	+	
A-30	t	0	+	
B-13	0	0	0	
B-18	t	0	0	
B-22	0	0	0	
B-26	t	0	+	
C-8	+b	0	0	
C-10	+	0	0	
C-12a	+m	0	0	
C-12c	+m	0	0	
C-14	+m	0	0	
C-16	+	0	0	
C-21	t	0	+	
C-30	t	0	+	
C-31	t	0	+	
D-4	0	0	0	?-Halloysite
D-8	t	0	0	
D-13	t	0	0	
D-15	+	0	0	
D-16	+	0	0	
Claw	+m	0	0	
D-26	+	0	0	
E-2	+	0	0	
E-8	+m	0	0	
E-13	+m	0	0	
E-14	+	0	0	
E-17	t	0	0	
E-17a	t	0	+	
F-3	t	t	0	I/S mix
F-8	+	+	0	I/S mix
F-15	+	0	0	
F-18	+	t	0	I/S mix
F-25	+b	0	0	

TABLE A.1—Continued

Sample number	Smectite	Illite	Kaolinite	Other
F-30	+	0	0	
F-32	+m	0	0	
F-34	+	0	0	
F-36	+	0	0	
F-47	+m	0	0	
F-50	+b	0	0	
F-51	+	0	0	
F-53	t	0	0	
F-55	t	0	?	
F-56	t	0	+	
G-1	0	+	0	Dolomite
G-4	0	+	0	Dolomite
G-5	0	t	0	Calcite
G-7	0	0	0	Calcite
G-12	0	0	0	Calcite
G-14	0	t	0	Calcite
G-19	0	+	0	Calcite
G-21	0	+	0	Calcite
G-24	0	+	0	Calcite
G-25	0	+	0	Calcite
G-27	0	+	0	t-Calcite
H-2	0	+	0	
H-5	0	+	0	
H-8	0	+	0	t-Calcite
H-10	0	+	0	
H-16	+b	0	0	
H-18	+	0	0	
H-25	+	0	0	
H-27	+	0	0	
H-28	+	0	0	
H-30	+	0	0	
H-31	+	0	0	
H-32	+	?	0	
J-2	0	t	0	
J-7	0	+	0	Calcite
J-10	0	+	0	Calcite
J-13	0	+	0	
J-14	0	+	0	Calcite
J-16	0	+	0	

TABLE A.1—Continued

Sample number	Smectite	Illite	Kaolinite	Other
J-17	0	+	0	Calcite
J-20	+	0	0	t-Calcite
J-31	+	0	0	
J-32	+	0	0	
J-33	+	0	0	
J-34	+	0	0	
J-35	t	0	0	
J-37	+	0	+	
J-38	+	0	t	
K-3	0	t	0	Calcite
K-7	0	+	0	Calcite
K-8	0	+	0	
K-10	0	+	0	
K-14	0	+	0	Calcite
K-15	0	+	0	t-Calcite
K-20	0	+	0	Calcite
K-23	0	+	0	

Appendix B. Petrographic Data

TABLE B.1—Petrographic description of thin-section samples

Sample #	Description
<u>Unit A</u>	
J-9	Sandstone or mudclast conglomerate, angular to sub-angular, poorly sorted with calcite cement, some bedding, no chalcedony, contains rip up clasts of mud and reworked caliche nodules, Q=213, F=0, L=104
F-7	Sandstone, sub angular to sub rounded, well packed in a calcite cement, contains mostly quartz and some plagioclase, point count not performed for this sample
K-12	Sandstone, sub-angular to sub-rounded, well sorted and well packed in a calcite cement, bedding present, some quartz grains have interclasts, Q=269, F=1, L=8
F-13	Limestone, and calcareous mud, micritic, with some silt size grains, spar cement filled fractures and possible burrows
D-2	Caliche, globular calcareous mud with some silt size grains packed in a spar cement, no fossils present
E-2B	Caliche, globular nodules in a silty mud-supported cement, no fossils
<u>Unit B</u>	
D-7	Limestone, microcrystalline, contains ostracodes and burrows and or rhizomes filled with a spar cement, ostracodes are disarticulated shell halves
C-2	Sandstone, sub-angular to sub-rounded, close packed with calcite cement, contains fossils and chalcedony, Q=262, F=2, L=61
C-3	Sandstone, sub-angular to sub-rounded, well packed in a calcite cement, some quartz grains have overgrowths, Q=369, F=35, L=20
C-5	Sandstone, angular to sub-angular, poorly sorted with calcite cement, contains fossils, chert, chalcedony, some quartz grains have air bubbles, Q=220, F=2, L=82

TABLE B.1—Continued.

F-46	Sandstone, sub-angular to sub-rounded, close packed in calcite cement and mud matrix, contains well rounded monocrystalline quartz grains with some overgrowths, Q=258, F=2, L=22
AARG	Sandstone, sub-angular, poorly sorted and finely packed in a calcite cement and mud matrix, contains fossils and chalcedony, some quartz grains have inclusions, Q=163, F=3, L=39
<u>Unit C</u>	
A-10	Sandstone or mudclast conglomerate, angular to sub-angular, poorly sorted in a weak calcite cement, contains chalcedony and mica, Q=165, F=3, L=143
OPK	Sandstone, angular, loosely packed in a calcite cement and mud matrix, contains chalcedony and fossils, Q=233, F=0, L=56
A-17	Siltstone, quartz cemented
C-11	Siltstone, quartz cemented
A-8	Volcanic ash?, highly-altered fine grain with small needle like clasts
D-9	Chert/chalcedony, creamy to brown, opaque to translucent with relict algal material, burrows, and ostracodes?

TABLE B.2—Point count data from samples listed in Table B.1.

Variables	Quartz				Feldspar			Lithic	Other	
	Qmu	Qmn	Qp	Qt	Fp	Fo	Ft	Lt	Fos.	Mat.
Sample #										
A-10	28	113	24	165	3	0	3	143	6	183
C-3	38	301	30	369	32	3	35	20	0	106
claw	18	189	30	237	1	0	1	31	8	223
C-2	55	194	28	277	2	0	2	57	0	164
AARG	10	128	25	163	3	0	3	39	13	282
K-12	60	205	4	269	0	1	1	8	2	220
C-2p	41	172	49	262	2	0	2	61	0	175
OPK-p	22	135	76	233	0	0	0	56	1	211
A-10	21	73	37	131	10	0	10	120	3	236
F-46	38	175	45	258	2	0	2	22	0	218
J-9	23	162	28	213	0	0	0	104	2	182
C-5	25	71	124	220	0	2	2	82	3	192

	Total counts		Percents			Key	
	out of 500	Qt	Ft	Lt			
A-10	311	53	1	46	Q	Quartz	
C-3	424	87	8	5	mu	monocrystalline, undulose	
claw	269	88	<1	12	mn	monocrystalline, non-undulose	
C-2	336	82	1	17	p	polycrystalline	
AARG	205	80	1	19	Qt	total quartz	
K-12	278	97	<1	3	F	feldspar	
C-2p	325	81	<1	19	p	plagioclase	
OPK-p	289	81	0	19	o	orthoclase	
A-10	261	50	4	46	Ft	total feldspar	
F-46	282	91	1	8	L	lithic	
J-9	317	67	0	33	Lt	total lithic	
C-5	304	72	1	27	Fos.	fossils	
					Mat.	matrix and unknowns	

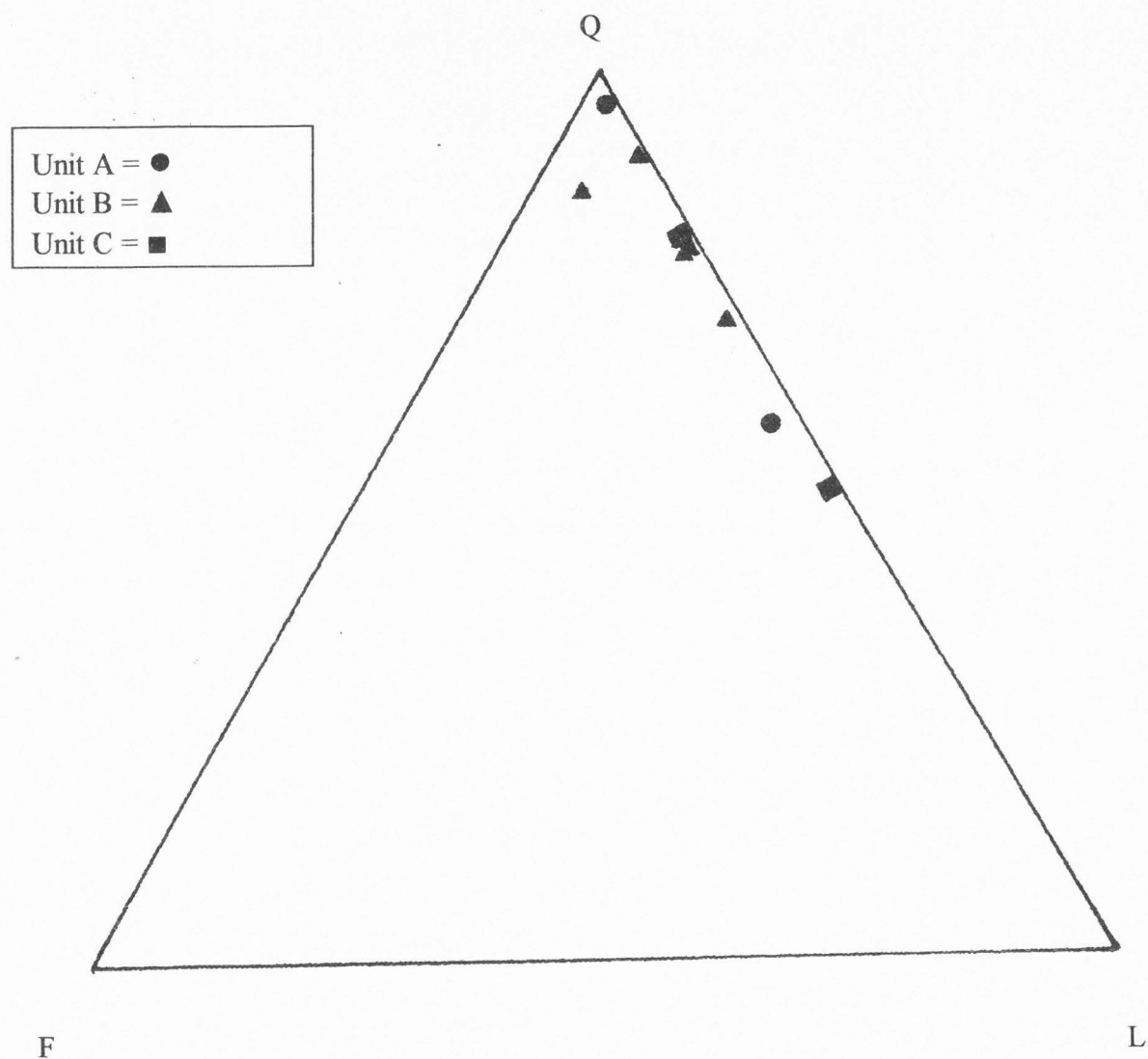


FIGURE B.1—QFL (total quartz, feldspars and lithics) diagram from a 500-point count petrographic analysis of sandstone samples listed in Table B.1 from the Morrison Formation at Como Bluff, Wyoming.

Appendix C. Quarry Data

Quarry list with data on taxa and taphonomy

Modern and current quarries under curation by WDIS

Note: Since many of these quarries are still actively being worked, locations are given to the section level to protect sites from vandalism. Contact the author or the Wyoming Dinosaur International Society for more accurate descriptions if needed for scientific research.

WDIS Quarry 1a, Bronte, T. 22 N., R. 77 W., Sec. 1, located in lower part of Unit A
Matrix is a dark gray-green mudstone. Vertebrate fossils are on average from smaller individuals. Most age groups are present. Skeletal parts are unsorted, disarticulated, associated and isolated. Some bone modification present.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

?sp. – one individual

Suborder: Theropoda

Allosaurus sp. shed tooth

Suborder: Ornithopoda

?sp. – 2 individuals

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis – 2 shed teeth

Order: Testudines

Suborder: Thecophora

Family: Pleurosternidae

?sp. – 2 individuals, two species

Class: Mammalia

?sp. – 1 individual

Invertebrata: Mollusca

?sp. – several thick shell pelecypods

WDIS Quarry 2b, Nail, T. 22 N., R. 77 W., Sec. 1, located just above caliche boundary in Unit B. Matrix is a fine greenish-gray blocky mudstone. Vertebrate fossils are mostly from adult animals. Skeletal parts partially sorted, disarticulated, associated and contain a high degree of chew marks.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Apatosaurus excelsus – 2 individuals

Camarasaurus sp. – up to 14 individuals

Diplodocus sp. – up to 14 individuals

- Brachiosaurus sp.* – 1 individual
- ?sp. – up to 14 individuals, species unknown
- Suborder: Theropoda
 - Allosaurus sp.* – up to 11 individuals
 - Allosaurus sp.* – 45+ shed teeth, all age groups (counted as 3 individuals)
 - Edmarka rex* – 3 individuals
- Suborder: Stegosauria
 - Stegosaurus sp.* – 1 individual
- Order: Rhynchocephalia
 - Opisthias sp.* – 1 individual
- Invertebrata
 - Conchostraca
 - Nestoria sp?* – 3 specimens

WDIS Quarry 3c, Claw, T. 22 N., R. 76 W., Sec. 5., located in Unit C. Matrix is a mud supported, non resistant conglomerate. Large vertebrate fossils are abraded beyond recognition. Small vertebrate fossils include most age groups and are unsorted, associated but dispersed and often broken.

Class: Reptilia

- Order: Saurischia
 - Suborder: Sauropoda
 - Camarasaurus sp.* – listed as one individual
 - Diplodocus sp.* – listed as one individual
 - Suborder: Theropoda
 - Allosaurus sp.* – shed tooth
 - Ceratosaurus sp.* – shed tooth
 - Coelurus sp.* – shed tooth
 - Megalosaurid – shed tooth
 - Dromiosaurid – shed tooth
- Order: Ornithischia
 - Suborder: Ornithopoda
 - Drinker nisti* – 2 individuals
 - Othneilia sp.* – 1 individual
 - Driosaurid – listed as one individual
- Order: Crocodilia
 - Suborder: Mesosuchia
 - Goniopholis sp.* – estimated 20 individuals and 300+ shed teeth
- Order: Testudines
 - Suborder: Thecophora
 - Family: Pleurosternidæ
 - Family: Baënidæ
 - ?sp. – possibly several individuals

Order: Rhynchocephalia

Opisthias sp. - 1 individual

Order: Creastodine - 6 individuals

Class: Osteichthyes

Subclass: Choanichthyes

Order: Dipnoi

Ceratodus robustus - listed as 6 individuals

Ceratodus sp. - new species, 3 individuals

Ceratodus sp. - new species #2, 14 individuals

Amioid - listed as 1 individual

Class: Mammalia

Order: Multituberculata

Zophia brentbaatar - 2 individuals

?Order: - one unknown non multituberculate

Invertebrata

Pelecepoda ?sp. - 1 shell fragment

WDIS Quarry, 4a, Bertha, T. 22 N., R. 76 W., Sec. 6?, located in Unit A. Matrix is a fine grained sandstone. Sauropod fossil is an adult single individual. Skeletal material is unsorted, partially articulated with some breakage.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Eobrontosaurus yahnahpin - also known as *Apatosaurus yahnahpin*, 1 individual

Suborder: Theropoda

Allosaurus sp. - 1 shed tooth

Order: Ornithischia

Suborder: Ornithopoda

Driosaurid - listed as 1 individual

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis sp. - 3 shed teeth

Invertebrata

Conchostraca

Nestoria sp? - one specimen

WDIS Quarry 5a, Joseph, T. 22 N., R. 76 W., Sec. 6, located in Unit A. Matrix is a fine grained sandstone. Sauropod fossil is from a young adult individual. Skeletal material is unsorted and partially articulated with no apparent bone modification.

Class: Reptilia

- Order: Saurischia
 - Suborder: Sauropoda
 - Eobrontosaurus yahnahpin* – also known as *Apatosaurus yahnahpin*, 1 individual
- Order: Crocodilia
 - Suborder: Mesosuchia
 - Goniopholis* sp. – 1 shed tooth

WDIS Quarry 6c, Becky, T. 22 N., R. 76 W., Sec. 5 or 6, located in Unit C. Matrix is a dark gray mudstone. Vertebrate fossils are from most age groups. Skeletal material is unsorted but oriented, partial to completely articulated and no bone modifications.

- Class: Reptilia
 - Order: Ornithischia
 - Suborder: Ornithopoda
 - Drinker nisti* – 13 individuals

WDIS Quarry 7c, OPK, T. 22 N., R. 76 W., Sec. 5 or 6, Located in Unit C. Matrix is a semi resistant conglomerate. Vertebrate fossils are from most age groups. Skeletal material is unsorted, disarticulated, associated and dispersed with minor amounts of bone modification.

- Class: Osteichthyes
 - Subclass: Choanichthyes
 - Order: Dipnoi
 - Ceratodus robustus* – listed as 1 individual
 - Ceratodus fossanovum* – listed as 1 individual
 - Ceratodus* sp. – new species #2, 3 individuals

- Class: Mammalia
 - Order: Multituberculata
 - Zophia brentbaatar* – 1 individual

- Class: Reptilia
 - Order: Testudines
 - Suborder: Thecophora
 - Family: Baenidae
 - ?sp – possibly several individuals

WDIS Quarry 8c, AARG, T. 22 N., R. 76 W., Sec. 6, located in Unit C south of Truck Quarry. Matrix is a semi resistant conglomerate. Vertebrate fossils are primarily from smaller individuals of most age groups. Skeletal material is from only a few parts of many animals that are associated but highly dispersed and with a good amount of bone modification.

- Class: Osteichthyes
 - Subclass: Choanichthyes
 - Order: Dipnoi
 - Ceratodus* sp. – 2 teeth plates, species unknown
- Class: Reptilia
 - Subclass: Testudines
 - Suborder: Thecophora
 - Family: Pleurosternidæ
 - Family: Baënidæ
 - ?sp. – various shell material
- Invertebrates
 - Pelecepoda
 - ?sp – near complete thin-shelled clam

WDIS Quarry 9a, Nasa, T. 22 N., R. 76 W., Sec. 4, located in Unit A in a sheet sandstone. Vertebrate fossils are from medium to large animals most of which are adults but some juvenile material is present. Skeletal material is partially sorted, partial to disarticulated but associated. Bones are complete with some abrasions present.

- Class: Reptilia
 - Order: Saurischia
 - Suborder: Sauropoda
 - Camarasaurus* sp. – 1 individual
 - Diplodocus* sp. – 1 individual
 - Suborder: Theropoda
 - Allosaurus* sp. – 1 very large specimen, may be new species
 - Order: Ornithischian
 - Suborder: Stegosauria
 - Stegosaurus* sp. – 1 individual
 - Suborder: Ornithopoda
 - Camptosaurus* sp. – listed as 3 individuals
 - Order: Crocodilia
 - Suborder: Mesosuchia
 - Goniopholis* sp. – 3 shed teeth
 - Order: Testudines
 - Suborder: Thecophora
 - Family: Pleurosternidæ
 - Family: Baënidæ
 - ?sp. – 2 individuals, 2 species unknown

WDIS Quarry 10c, Truck, T. 22 N., R. 76 W., Sec. 6., located in Unit C. Matrix is a nonresistant mudstone. Vertebrate fossils are primarily from smaller individuals with most age groups present. Skeletal material is partially sorted, associated but dispersed with a high degree of bone modification.

- Class: Reptilia
 Order: Saurichia
 Suborder: Sauropoda
 ?sp. - listed as one individual, species unknown
 Suborder: Theropoda
 Allosaurus sp. - shed teeth
 Megalosaurid - shed teeth
 Ceratosaurus sp. - shed teeth
 Order: Ornithischia
 Suborder: Ornithopoda
 Drinker nisti - listed as one individual
 Order: Crocodilia
 Suborder: Mesosuchia
 Goniopholis sp. - shed teeth
 Order: Testudines
 Suborder: Thecophora
 Family: Baenidae
 ?sp. - possibly several individuals

- Class: Osteichthyes
 Subclass: Choanichthyes
 Order: Dipnoi
 Ceratodus ?sp. - tooth plate fragment

WDIS Quarry 11a, Debra, located in Unit A. Matrix is a non-resistant mudstone. Vertebrate fossils are from a single adult individual that was disarticulated but associated. Bone modification is minor.

- Class: Reptilia
 Order: Testudines
 Suborder: Thecophora
 Family: Pleurosternidae
 ?sp. - 1 individual

WDIS Quarry 12a, Morton, T. 22 N., R. 76 W., Sec. 5 or 6, located in Unit A. Matrix is a red and green mottled paleosol. Vertebrate fossils are from a single adult individual. Skeletal material is partially sorted, disarticulated but associated and encrusted with calcareous concretions.

- Class: Reptilia
 Order: Saurischia
 Suborder: Sauropoda
 Camarasaurus sp. - 1 individual, species unknown

WDIS Quarry 13c, Sean, T. 22 N., R. 76 W., Sec. 5., located in Unit C in blocky gray

green mudstone. Croc teeth show some orientation preference to the north. Vertebrate fossils are from extra small, mostly adult individuals. Skeletal material is very fragile, unsorted, disarticulated but unassociated with some degree of bone modifications.

Class: Reptilia

Order: Saurischia

Suborder: Theropoda

Coelurus sp. – 1 shed tooth

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis – listed as 11 individuals

Order: Testudines

Suborder: Thecophora

Family: Baenidae

Dorsetochelys buzzops – 1 individual

?sp. – 2 individuals, species unknown

Order: Pterosauria

Pterosaur – 1 individual

Order: Rhynchocephalia

Opisthias sp. – 1 individual

Order ? – 3 individual lizard-like species

Class: Osteichthyes

Subclass: Choanichthyes

Order: Dipnoi

Ceratodus sp. – listed as 1 individual, species unknown

Subclass: ?

Amioid – listed as 1 individual

Class: Mammalia

Order: Multituberculata

Zophia brentbaatar – 2 individual

Order: Altoconodontid

Alticonodontid – 1 individual

Mammal – 1 individual, species unknown

WDIS Quarry 14c, Bernice, T. 22 N., R. 76 W., Sec. 5., located in Unit C just west of Sean Quarry. Matrix is a soft non resistant sandstone. Vertebrate fossils include an extra large adult and fragments from a few extra small adults. Skeletal material is unsorted and partially articulated a fair to minor amount of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauripoda

Apatosaurus sp. – 1 individual, species unknown

- Order: Testudines
 - Suborder: Thecophora
 - Family: Baënidæ
 - Uluops uluops* – 1 individual
 - ?sp. – listed as 1 individual
- Order: ?
 - Creastadine – listed as 1 individual

WDIS Quarry 15c, Japath, T. 22 N., R. 76 W., Sec. 5, located in Unit C. Matrix is a gray blocky mudstone. Vertebrate fossils are from large mostly adult individuals. Skeletal material is unsorted, isolated and dispersed with a high degree of bone modification.

- Class: Reptilia
 - Order: Saurischia
 - Suborder: Sauripoda
 - ?sp. – 1 individual
 - Suborder: Theropoda
 - Ceratosaurus* sp. – 2 shed teeth

WDIS Quarry 16a, Silver Back, T. 22 N., R. 76 W., Sec. 5, located in Unit A. Matrix is a fine grain sandstone. Vertebrate fossils are from a small adult individual. Skeletal material is unsorted, associated but dispersed with a good amount of bone modification.

- Class: Reptilia
 - Order: Saurischia
 - Suborder: Sauripoda
 - ?sp. – 1 individual

WDIS Quarry 17a, Roco, T. 22 N., R. 76 W., Sec. 4 or 5, located in Unit A. Matrix is a fine grain sandstone. Vertebrate fossils are from a medium sized adult individual. Skeletal material is partially sorted, disarticulated but associated with a minor amount of bone modification.

- Class: Reptilia
 - Order: Ornithischia
 - Suborder: Ornithopoda
 - Driosaurus* sp. – 1 individual, species unknown

WDIS Quarry 18a, Matt, T. 22 N., R. 76 W., Sec. 5., located in Unit A. Matrix is a red and green mottled paleosol. Fossil is associated and disarticulated.

- Class: Reptilia
 - Order: Saurischia

Suborder: Sauropoda

Camarasaurus sp. – 1 individual, species unknown

WDIS Quarry 19a, EP Thompson, T. 22 N., R. 76 W., Sec. 4, located in Unit A. Matrix is a fine grain sandstone. Vertebrate fossils are from a single extra large adult individual. Skeletal material is isolated, associated and dispersed with minor amounts of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Diplodocus sp. – 1 individual

WDIS Quarry 20c, Blue Nimbus, T. 22 N. R., 76 W., Sec.5, located at the contact between Unit B and Unit C. Matrix is a semi resistant green siltstone. Vertebrate fossils are from several adult extra small individuals. Skeletal material contain few parts of an individual that are associated and dispersed. Bone modification is minor.

Class: Osteichthyes

Subclass: Choanichthyes

Order: Dipnoi

Ceratodus sp. – new species #2, 1 individual*Ceratodus* sp. – 2 individuals, species unknown

Class: Mammalia

Subclass: Alticonodontid - 1 individual

Class: Reptilia

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis sp. – listed as 4 individuals

WDIS Quarry 21a, BDraw, T. 22 N., R. 76 W., Sec 5, located in Unit A. Matrix is a thin channel-like sandstone. Vertebrate fossils are mostly from a single extra large individual. Skeletal material is just a few parts of the individual that is associated but dispersed with a good amount of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

?sp. – 1 individual, species unknown

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis sp. – 2 shed teeth

WDIS Quarry 22b, Double Dip, T. 22 N., R. 77W., Sec. 1, located in Unit B. Matrix is a gray green mudstone. Vertebrate fossils are from a single adult extra large individual. Skeletal material consists of a few isolated and dispersed bones that have some bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Diplodocus sp. – 1 individual, species unknown

WDIS Site 23c, EoS, T. 22 N., R. 76 W., Sec. 5, located in Unit C. Matrix is a dark gray mudstone. The fossil is an unusually large isolated shed tooth.

Class: Reptilia

Order: Saurischia

Suborder: Theropoda

Megalosaurid – 1 shed tooth, species unknown

WDIS Quarry 24c, Wkat, T. 22 N., R. 76 W., Sec. 6, located in Unit C just west of OPK. Matrix is a gray mudstone. Vertebrate fossils are from an extra large adult. Skeletal material contains a few parts that are associated but dispersed with a good amount of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Apatosaurus sp. – 1 individual, species unknown

Suborder: Theropoda

Ceratosaurus sp. – 1 shed tooth

WDIS Quarry 25a, Fredlin, T. 22 N., R. 77 W., Sec. 1, located in Unit A just below the caliche boundary. Matrix is a red and green mottled paleosol. Most vertebrate fossils are from an extra large adult individual. Skeletal material is partially sorted, disarticulated but associated with a high degree of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Camarasaurus sp. – 1 individual, species unknown

Suborder: Theropoda

Allosaurus sp. – 2 shed teeth

WDIS Quarry 25a, Mel's Femur, T. 22 N., R. 76 W., Sec. 6, located in Unit A in sandstone lens. Vertebrate fossils are from large to extra large adult individuals. Skeletal material is partially sorted, disarticulated but associated with a high degree of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Diplodocus sp. – 1 individual

Suborder: Theropoda

Allosaurus sp. - shed tooth and toe claw

WDIS Quarry 26a, Mojo, T. 22 N., R. 76 W., Sec 5, located in Unit A. Matrix is a mottled red and green paleosol. Vertebrate fossils are from an extra large adult individual. Skeletal material contains a few parts that are disarticulated and dispersed with a fair amount of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Camarasaurus sp. – 1 individual

WDIS Quarry 27a, EBS, T. 22 N., R. 76 W., Sec. 5, located in Unit B. Matrix is a gray mudstone. Vertebrate fossils are from large adult individual. Skeletal material is a few parts that is isolated and poorly preserved with a fair amount of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

?sp. – 1 individual

WDIS Quarry 28b, 2 Legs, T. 22 N., R. 76 W., Sec. 5, located in Unit C. Matrix is a gray mudstone. Vertebrate fossils are from an extra large adult individual. Skeletal material consists of a single isolated bone with a fair amount of bone modification.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Diplodocus sp. – 1 individual

WDIS Quarry 29c, Kat, T. 22 N., R. 76 W., Sec. 6, located in Unit C. Matrix is a gray mudstone. Vertebrate fossils are from a single adult individual. Taphonomy is unclear and thus not classified.

Class: Reptilia
 Order: Saurischia
 Suborder: Sauropoda
Camarasaurus sp – 1 individual

WDIS Quarry 30c, Julie, T. 22 N., R. 76 W., Sec. 5 or 6, located in Unit C. Matrix is a dark gray mudstone. Vertebrate fossil is a partially articulated and still being excavated. Taphonomy was not available at this time.

Class: Reptilia
 Order: Ornithischia
 Suborder: Ornithopoda
Drinker nisti – 1 individuals

WDIS Quarry 31a, ADB, T. 22 N., R. 77 W., Sec. 1, located in Unit A west of Nail Quarry. Matrix is a fine grain sandstone. Vertebrate fossils are from a single adult individual. Skeletal material appears to be disarticulated but associated. Most material was recovered as float.

Class: Reptilia
 Order: Ornithischia
 Suborder: Stegosauria
Stegosaurus sp. – 1 individual

WDIS Quarry 32a, DFG, T. 22 N., R. 77 W., Sec. 1, located in Unit A. Matrix is a microcrystalline limestone. Plat fossils are replaced with silica and was preserved in situ. Invertebrates are re-crystallized with calcite and may have a silica endocast.

Plantea:
 Spenophyta
 Equisetum L.
 Equisetum sp.
 Filicophyta
 Unidentified fern
 Coniferophyta
 Brachyphyllum sp.

Invertebrata:
 Molluska
 Lymnaea ativuncula
 Lymnaea morrisonensis
 Amplivalvata cyclostoma

WDIS Quarry 33a, Jane Austin, T. 22 N., R. 77 W., Sec. 1, located in Unit A.

Ichnofossils include many adult and young adult individuals. Some orientation is present.

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

cf. *Brontopodus* or *Parabrontopodus*

Suborder: Theropoda

cf. – type not identified

Order: Ornithischia

cf. *Anomoepus*

WDIS Quarry 34a, Ramona, T. 22 N., R. 76 W., Sec. 4, located in Unit A. Matrix is a Fine-grained sandstone bed. Fossils are preserved as casts and molds.

Invertebrata:

Molluska – several clam burrows with some shell impressions at the base of each burrow

Vertebrata:

Coprolites of unknown origin

Plantae:

Root casts from large plants possibly trees or tree ferns

WDIS Quarry 35b, Bronto Snail, T. 22 N., R. 76 W., Sec. 5, located in Unit B. Matrix is a micritic limestone. Fossils are re-crystallized with calcite with calcite endocasts.

Invertebrata:

Molluska

Viviparus morrisonensis – several specimens

Aplovalvata scabrida

Insectivora:

Insect larval or cocoon casts

WDIS Quarry 36x, Ellen, T. 22 N., R. 76 W., Sec. 5, located in Cloverly Formation. Matrix is a brownish kaolinitic carb-shale. Fossils are mostly carbon films, molds and casts.

Plantae:

Coaly shale with various leaves and seed pods.

Historic quarry list from Ostrom and McIntosh (1966)

Note: Taphonomy data was not given.

Reed's YPM Quarry 4, T. 22 N., R. 76 W., Sec. 5, located at the top of Unit B. Matrix is

a conglomerate.

- Class: Reptilia
 - Order: Saurischia
 - Suborder: Sauropoda
 - Apatosaurus sp.*
 - Camarasaurus sp.*
 - Barosaurus sp.*
 - Suborder: Theropoda
 - Antrodemus valens*
 - Order: Ornithischia
 - Suborder: Stegosauria
 - Stegosaurus sp.*

Reed's YPM Quarry 9, T. 22 N., R. 77 W., Sec. 12, located in Unit B. Matrix is a gray green mudstone.

- Class: Osteichthyes
 - Subclass: Choanichthyes
 - Order: Dipnoi
 - Ceratodus guntheri*
- Class: Amphibia
 - Order: Anura
 - Suborder: Aglossa?
 - Eobatrachus agilis*
 - Suborder: Neobatrachia
 - Comobatrachus aenigmatis*
 - Order: Urodela
 - Comonecturoides marshi*
- Class: Reptilia
 - Order: Chlonia
 - Suborder: Amphichelydia
 - Glyptops ornatus*
 - Order: Crocodilia
 - Suborder: Mesosuchia
 - Goniopholis sp.*
 - Order: Thynchocephaliea
 - Opisthias rarus*
 - Theretairus antiquus*
 - Order: Saurischia
 - Suborder: Sauropoda
 - Camarasaurus sp.*
 - Suborder: Theropoda
 - Coelurus fragilis*

Antrodemus valens

Order: Ornithischia

Suborder: Ornithopoda

*Laosaurus gracilis**Laosaurus ?consors**Laosaurus celer**Dryosaurus sp.**Camptosaurus sp.*

Suborder: Stegosauria

Stegosaurus sp.

Order: Squamata

Suborder: lacertilia

Cteniogynys antiquus

Order: Crocodilia or Eosuchia?

Suborder: Mesosuchia or Choristodera?

Macellognathus vagans

Class: Aves?

Laopterys priscus

Class: Mammalia

Order: Multituberculata

*Ctenacodon serratus**Ctenacodon nanus**Ctenacodon scindens**Ctenacodon laticeps**Psalodon potens**Psalodon fortis**Psalodon marshi*

Order: Troconodonta

*Phascolodon gidleyi**Aploconodon comoensis**Trioracodon bisulcus**Priacodon ferox**Priacodon robustus**Priacodon hulli**Priacodon grandaevus*

Order: Symmetrodonta

*Tinodon bellus**Menacodon rarus**Amphidon superstes**Eurylambda aequicrurius*

Order: Pantotheria

*Paurodon valens**Archaeotrigon brevimaxillus**Archaeotrigon distagmus**Tathiodon agilis*

Dryolestes priscus
Laolestes eminens
Laolestes vorax
Laolestes grandis
Laolestes segnis
Amblotherium gracilis
Laodon venustus
Amblotherium dbilis
Herpetairus arcuatus
Herpetairus humilis
Herpetarius obstusus
Melanodon oweni
Melanodon goodrichi
Euthlastus cordiformis
Miccyclotryrans minimus
Malthacolestes osborni
Pelicopsis dubius
Stylacodon validus

Order: Docodonta

Docodon victor
Docodon striatus
Docodon crassus
Docodon affinis
Docodon superus

Reed's YPM Quarry 13, T. 22 N., R. 76 W., Sec. 4 or 5, located in Unit A. Matrix unknown.

Class: Reptilia

Order: Saurishchia

Suborder: Sauropoda

Camarasaurus lentus
Diplodocus sp.

Suborder: Theropoda

Coelurus agilis
Coelurus fragilis

Order: Ornithischia

Suborder: Ornithopoda

Camptosaurus dispar
Camptosaurus medius
Camptosaurus nanus
Camptosaurus browni
Camptosaurus depressus
Laosaurus sp.

Suborder: Stegosauria

Stegosaurus affinis
Stegosaurus sulcatus
Stegosaurus stenops
Stegosaurus unguatus
Stegosaurus laticeps (Diracodon)

Order: Chelonia
Suborder: Amphichelydia
Glyptops plicatulus
Order: Crocodilia
Suborder: Mesosuchia
Goniopholis sp.

Brown's YPM Quarry B, T. 22 N., R. 76W., Sec. 5, located in Unit A. Matrix unknown.

Class: Reptilia
Order: Ornithischia
Suborder: Stegosauria
Stegosaurus sp.

Brown's YPM Quarry C, T. 22N., R. 76 W., Sec. 5, located in Unit A. Matrix unknown.

Class: Reptilia
Order: Saurischia
Suborder: Theropoda
Antrodemus valens

Brown's YPM Quarry D, T. 22N., R. 76 W., Sec. 5, located in Unit A. Matrix unknown.

Class: Reptilia
Order: Saurischia
Suborder: Theropoda
Antrodemus valens

TABLE C.1—Taphonomic scores from quarry data using the taphonomic criteria listed in Table 1.

Variables	Quarry name																											
	WDIS																											
Taphonomy	1a	2b	3c	4a	5a	6c	7c	8c	9a	10c	11a	12a	13c	14c	15c	16a	17a	18a	19a	20c	21a	22b	24c	25a	26a	27a	28b	
Assemblage Data																												
Body size	2	5	2	5	5	2	2	2	4	2	1	5	1	5	4	2	3	5	5	1	5	5	5	5	5	4	5	
Age spectrum	3	4	3	5	5	3	3	3	5	3	5	5	4	5	4	5	5	5	5	5	5	5	5	5	5	5	5	
Skeletal parts	1	2	1	1	1	1	1	4	2	2	1	2	1	1	1	1	2	5	5	4	4	5	4	2	4	4	5	
Bone articulation	3	3	4	2	2	1	4	4	3	4	3	3	4	2	5	4	3	5	4	4	3	5	3	3	3	3	5	
Bone Modification																												
Breakage	3	2	3	3	1	1	3	3	1	3	2	3	3	3	4	3	2	3	2	2	3	2	3	3	2	2	3	
Abrasion	1	1	5	1	1	1	2	1	2	3	1	1	1	1	4	3	1	1	1	1	2	1	2	1	2	1	1	
Surface marks (punctures, scratches etc)	1	5	3	1	1	1	2	1	1	2	1	2	2	2	2	1	1	1	1	2	2	2	3	4	2	2	3	
number individuals <i>n</i>	8	64	67	4	2	35	7	4	12	7	1	1	24	3	2	1	1	1	1	8	2	1	2	2	1	2	1	
number of species <i>k</i>	7	9	21	4	2	1	5	3	10	7	1	1	12	3	2	1	1	1	1	4	2	1	2	2	1	2	1	

Appendix D. Stratigraphic Sections

Stratigraphic Sections, (see Figure 1 for detailed locations)

Thickness in Meters	Description
Section East – T. 22 N., R. 76 W., Sec. 4, Albany County, Wyoming	
Cloverly Formation (in part)	
5+	Chert pebble conglomerate in a matrix of poorly sorted sand, pale yellow-tan or gray 5YR 5/1, large scale cross beds, basal contact appears non conformable
Morrison Formation, 75 + Meters thick	
Unit C	
6.5	Mudstone, olive black 5Y 2/1, blocky at top and platy at base, non calcareous, smectitic
17.5	Mudstone, dark greenish gray 5GY 4/1, weathered but appears blocky, non calcareous to partially calcareous, smectitic
.3	Chert, clear to creamy brown, blends laterally into micritic limestone and green quartz cemented siltstone
Unit B	
20.7	Mudstone, light olive gray 5Y 7/1 to 5Y 6/1, blocky, calcareous, with 4 beds approximately 0.2 meters thick of lenticular, massive micritic limestone, some fossiliferous, smectitic
Unit A	
6	Mudstone and paleosols, light olive gray with variegated lenses of light brownish gray 5YR 6/1 to grayish red 5R 4/2, paleosols contain caliche nodules that thicken upward in section, illitic
2	Sandstone, yellowish gray 5Y 8/1, fine grain, calcareous, with some thin mud lenses or drapes, rip up clasts at base
4.8	Mudstone and paleosols, light olive gray with variegated lenses of light brownish gray 5YR 6/1 to grayish red 5R 4/2, paleosols contain caliche nodules, root casts and burrows, illitic
2.2	Sandstone, yellowish gray 5Y 8/1, fine grain, channel-like, calcareous, with rip up clasts at base, also contains clam beds and burrow structures

- 4 Mudstone and paleosols, same as above
- 2 Sandstone, yellowish gray 5Y 8/1, channel-like, same as above
- 5 Mudstone and paleosols, same as above
- .8 Sandstone, same as above
- 2.2 Mudstone and paleosols, same as above

Lower contact covered

Section Central – T. 22 N., R. 76 W, Sec. 5, Albany County, Wyoming

Cloverly Formation (in part)

- 5+ Chert pebble conglomerate in a matrix of poorly sorted sand, pale yellow-tan or gray 5YR 5/1, large scale cross beds, basal contact appears non conformable
- 3 Mudstone, brownish gray 5YR 4/1 to dark olive black 5Y 2/1, plastic, flaky, non calcareous, kaolinitic, lower contact may be conformable

Morrison Formation – 88+ Meters thick

Unit C

- 14 Mudstone, Olive gray 5Y 4/1, non calcareous, silty lenses, platy at top and blocky at base, base contains calcite nodules some 0.2 meters in diameter, smectitic
- .8 Chert, translucent brown, interfingers with limestone and siltstone

Unit B

- 2 Sandstone, yellowish gray 5Y 8/1, very fine grain with clay lenses, non resistant, limonite and iron staining
- 9 Mudstone, alternating dark greenish gray 5G 4/1 to green gray 5GY, lighter beds are silty, darker beds contain gypsum crystals, platy and mildly calcareous, also contains a thin bed 0.2 meters thick of translucent brownish chert, smectitic
- .2 Limestone, gray, micritic, semi resistant, lenticular
- 14.8 Mudstone, greenish gray 5GY 6/1, lightly calcareous, mostly blocky with some platy lenses, contains thin tabular to lenticular lenses of micritic limestone and chert beds, smectitic

- .5 Sandstone, yellowish gray 5Y 8/1, very fine grain, semi to non resistant
- Unit A
- 6.5 Mudstone and paleosol, greenish gray 5GY 6/1 variegated with grayish red 5R 4/2, blocky, partially calcareous with caliche nodules, illitic/smectitic
- 6.2 Mudstone and lenticular beds of sandstone mixed, greenish gray 5GY 7/1 blocky and calcareous mudstone, sandstone is buff or grayish yellow 5Y 8/1, fine grained non to mildly resistant, rip up clasts, laminar and some trough cross stratifications, illitic
- 3.5 Mudstone and paleosols, same as above
- 12.5 Sandstone, grayish yellow 5Y 8/1, fine grain, several stacked sheet like beds, calcareous, bedding is laminar and trough cross stratified, resistant and semi resistant, partially covered
- 14.5 Mudstone and paleosols, with a small thin lens of sandstone, partially covered, same as above
- 3+ Limestone and thin lenses of mudstone, micritic, basal unit is massive with mudmounds and stromatolites

Lower contact covered

Section West – T. 22 N., R. 77 W., Sec. 1, Albany County, Wyoming

Cloverly Formation

- 3+ Chert pebble conglomerate in a matrix of poorly sorted sand, pale yellow-tan or gray 5YR 5/1, large scale cross beds, basal contact appears non conformable

Morrison Formation – 82 Meters

Unit C

- 1 Mudstone, olive black 5Y 2/1, blocky, with a reddish brown luster, non calcareous
- 6 Mudstone, greenish gray 5GY 4/1 to yellowish brown 10YR 6/2, silty, non calcareous, blocky
- 1 Chert, translucent brown, contains spherical structures, ostracodes?

- 18.5 Mudstone, medium gray N4 to greenish gray 5GY 4/1, platy, waxy, generally non calcareous, calcite nodules at base 0.04 meters in diameter
- Unit B
- .5 Chert, same as above
- 6.5 Mudstone, greenish gray 5GY 6/1, blocky, partially calcareous
- .5 Limestone, micritic, lenticular, crumbly
- 4.5 Mudstone, greenish gray 5GY 6/1, blocky at top but platy at base, contains large up to .1 meter in diameter calcareous concretions, smectitic
- 2 Sandstone lenses, gray yellow 5Y 8/1, fine grain, with laminar and cross beds, calcareous in a platy mudstone, greenish gray 5GY 6/1
- 3 Mudstone, greenish gray 5GY 6/1, blocky, illitic
- Unit A
- .5 Paleosol and caliche bed, grayish red 5R 4/2, calcareous, illitic
- 4 Sandstone, grayish yellow 5Y 8/1, non resistant, calcareous, no bedding planes visible
- 8 Mudstone, greenish gray 5GY 4/1, blocky, waxy, partially calcareous, illitic
- 16 Mudstone and paleosols, greenish gray 5GY 4/1 and grayish brown 5YR 3/2 to grayish red purple 5RP 4/2, calcareous, illitic, contains caliche and thin lenses of semi resistant sandstone up to .8 meters thick, grayish yellow 5Y 8/1, weathered surface often has a reddish tint, cross beds present with rip up clasts at base,
- 6 Mudstone with alternating beds of limestone, greenish gray 5GY 4/1, blocky, calcareous, illitic, limestone is micritic and highly fossiliferous
- Windy Hill Member
- 4 Sandstone, yellow 5Y 8/1, fine grain, glauconitic, massive, semiresistant, cross beds present, topped with a blocky mudstone, calcareous and dolomitic, lower contact appears conformable

Sundance Formation (in part)

Redwater Shale Member

- 3+ Shale, greenish gray 5G 6/1, glauconitic, illitic, dolomitic, non resistant with thin lenses of sandstone and fossiliferous limestone

Section A – T. 22. N., R. 76 W., Sec. 5 or 6, Albany County, Wyoming

Cloverly Formation (in part)

- 3+ Chert pebble conglomerate in a matrix of poorly sorted sand, pale yellow-tan or gray 5YR 4/1, large scale cross beds, basal contact appears non conformable
- 5 Mudstone, silty, brownish gray 5YR 5/1, platy with plant fragments and or coal lenses, non to low calcareous, kaolinitic, lower contact may be conformable

Morrison Formation (in part)

Unit C

- 4 Mudstone, pale yellowish brown 10YR 6/2, non calcareous, platy, smectitic
- 9.5 Mudstone, greenish gray 5GY 6/1, platy at top, blocky at base, smectitic
- 1 Mudstone conglomerate, non resistant, highly fossiliferous, no apparent bedding planes, mud supported, smectitic
- 11.5 Mudstone, greenish gray 5GY 6/1, platy with some blocky lenses, same as above, also contains a thin non persistent lens of sandstone/conglomerate and chert, smectitic

Unit B

- 6.5 Mudstone, greenish gray 5GY 6/1 to olive black 5Y 2/1, platy, mostly calcareous, smectitic
- 5.5 Mudstone, silty, greenish gray 5GY 6/1, smectitic, with thin lenses of limestone and chert up to 0.5 meters thick

Unit A

- 2 Mudstone and paleosols, greenish gray 5GY 6/1 to reddish brown gray 5YR 6/1, illitic, with caliche nodules

Section B – T. 22 N., R. 76 W., Sec. 6, Albany County, Wyoming

Cloverly Formation (in part)

3+ Chert pebble conglomerate in a matrix of poorly sorted sand, pale yellow-tan or gray 5Y 8/1, large scale cross beds, basal contact appears non conformable

6 Mudstone, olive gray to dark greenish gray 5Y 3/1 to 5GY 3/1, blocky, waxy, non calcareous, some plant material, kaolinitic, lower contact may be conformable

Morrison Formation (in part)

Unit C

17.5 Mudstone, olive gray 5Y 5/1, blocky, non calcareous, smectitic, with some thin chert and silty lenses, calcite nodules up to 0.2 meters in diameter occur at the base

Unit B

10 Mudstone, olive gray to greenish gray 5Y 3/1 to 5/1, partially calcareous, smectitic, blocky with thin lenses of limestone and sandstone, topped with a sandstone/conglomerate

Unit A

12.5 Mudstone and paleosols with caliche nodules, greenish gray 5GY 6/1, blocky, calcareous, illitic

3 Sandstone, yellowish gray 5Y 8/1, semiresistant, fine grain, low angle cross stratification

Section C – T. 22 N., R. 76 W., Sec. 6, Albany County, Wyoming

Cloverly Formation (in part)

3+ Chert pebble conglomerate in a matrix of poorly sorted sand, pale yellow-tan or gray 5YR 5/1, large scale cross beds, basal contact appears non conformable

7 Mudstone/shale, silty, pale yellow brown 10 YR 6/2, with plant debris and coal lenses, base is siltier with wood and mudclast, kaolinitic, lower contact may be conformable

Morrison Formation (in part)

Unit C

1.5 Mudstone, olive gray 5Y 4/1, blocky, non calcareous, smectitic

- 1.5 Mudstone, light brownish gray 5YR 5/1, blocky, smectitic, capped by a thin 2 cm thick chert bed with plant or algal structures
- 3 Mudstone, olive gray 5Y 4/1, same as above
- 1 Ash, weathered yellowish gray 5Y 8/1, calcareous, putty-like when wet, smectitic
- 9.5 Mudstone, light olive gray 5Y 5/1, platy, partially calcareous, smectitic, capped with a thin chert bed
- Unit B
- 6 Sandstone/conglomerate, pale yellow brown 10YR 6/1, semi- to non-resistant, calcareous cement, fossiliferous, possibly faulted
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Appendix E. Bibliography

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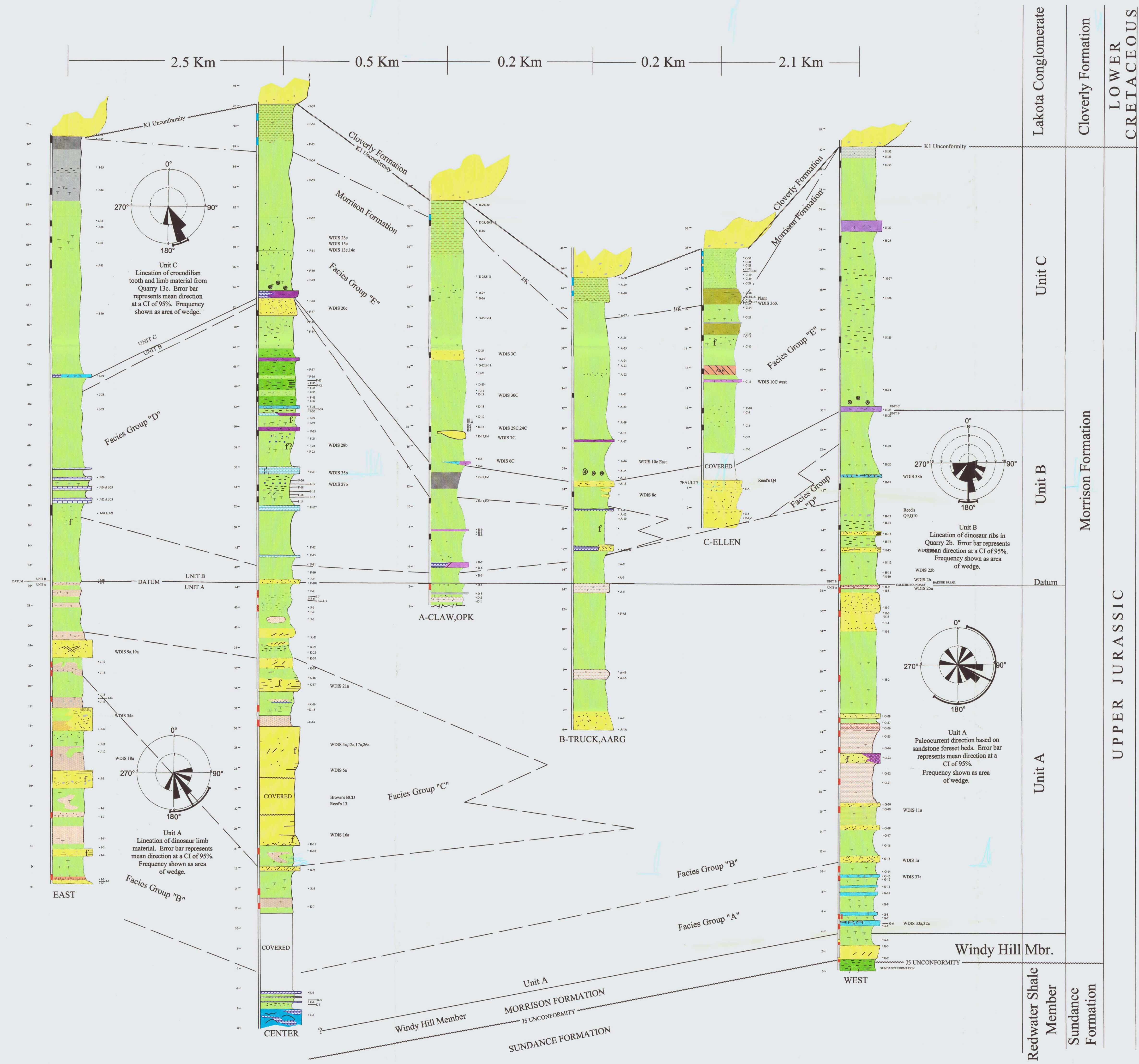
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Stratigraphic Sections of the Morrison Formation at Como Bluff, Wyoming

Illustrated by Arch Swank

Key	
Lithology	Symbols
Shale	f Fossil material as float
Sandstone	Caliche
Conglomerate	Platy
Chert	Blocky
Limestone	Cross beds
Paleosol	Concretions
Mudstone	Calcite nodules
	Clam beds
	Rip-up clasts
	Mud mounds
	Foot prints
	Mollusks
Clay codes	Sample #
Illite	WDIS 1a Quarry # (See Appendix C)
Illite/smectite mix	Facies Group boundaries
Smectite	Unit boundaries
Kaolinite	Unconformity
	J/K Jurassic/Cretaceous boundary
Column width represents weathering profile.	

Facies Group Descriptions

- A- **Lithofacies:** Platy greenish-gray illite rich mudstone with thin tabular, highly fossiliferous limestone beds
Taphofacies: Fossils are disarticulated but associated with little to no surface marks or abrasions; plant remains are permineralized with silica
Biofacies: Fauna is aquatic with smaller sized adult vertebrates, mollusks are common; aquatic plants include charophytes and stromatolites; other plants include ferns, equisetums, and conifers
- B- **Lithofacies:** Platy to blocky greenish-gray and red mottled illite rich mudstone and paleosols with thin (5 to 2 m thick), lenticular, semi resistant fluvial sandstone beds
Taphofacies: Vertebrate fossils are disarticulated with a low degree of association; bone modification is high with fractures, punctures and surface marks; bones and plants are poorly preserved
Biofacies: Fauna consists of large adult saurian dinosaurs such as *Camptosaurus*, turtles, crocodiles and mollusks
- C- **Lithofacies:** Thin tabular or splay-like sandstone containing laminar and mega ripple bedding in a caliche and illite rich red and green mottled paleosol and mudstone
Taphofacies: Large vertebrate fossils are partially articulated with a low degree of bone modification; smaller vertebrates are disarticulated and scattered also with a low degree of bone modification
Biofacies: Fauna is dominated by young and adult ornithomischian dinosaurs such as *Sigaus* and *Comptosaurus*; other vertebrates and invertebrates are less common or rare
- D- **Lithofacies:** Blocky greenish smectite rich mudstone with thin lenticular beds of limestone and chert; sandstone beds are present but rare
Taphofacies: Mega vertebrate fossils are disarticulated and are either isolated or highly concentrated with many individuals, most of which are adult or sub adult; all have a high degree of bone modification; rare localities contain micro vertebrates
Biofacies: Taxa include large saurian dinosaurs and less common ornithomischian dinosaurs, also present but rare are mammals, turtles, crocodiles, amphibians, lizards and lungfish
- E- **Lithofacies:** Platy and blocky darker gray to greenish gray smectite rich mudstone with occasional thin beds of chert and sandstone/conglomerate
Taphofacies: Vertebrates are often disarticulated and unassociated; large bone is highly abraded, smaller material may be broken but generally well preserved; accumulations exist in the conglomerates; fully articulated young to adult vertebrates of *Drinker* are found in the mudstone beds
Biofacies: Taxa are aquatic including the smaller ornithomischian dinosaurs such as *Drinker* and *Othello*; other vertebrates include lungfish and crocodiles with most age groups present, turtles, mammals and pterosaurs; mollusks and large dinosaurs are rare